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THE GEOLOGICAL SIGNIFICANCE AND GENETIC CLASSIFICATION OF ARKOSE DEPOSITS[1]

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Arkose has been held by different geologists to be significant respectively of several different types of conditions at the time of its formation. By Walther,[2] for instance, it is considered to be so distinctive of desert formations as to be, next to salt deposits, the the most important index of the desert origin of a formation. Mackie,[3] although not mentioning arkose by name, in his discussion of the significance of fresh feldspar in sediments seems to consider the rock especially characteristic of deposits that have formed under rigorous climatic conditions. Von Hauer[4] believes that arkose is especially characteristic of coal-bearing formations. Shaler[5] is of the opinion that it is formed when a granitic terrane, long under moist temperate climatic conditions, is exposed to more rigorous conditions or to marine or lacustrine transgression. Mansfield[6] believes, on the other hand, that the conditions for the formation

[1] Portion of a thesis accepted in partial fulfilment of the requirements for the degree of Doctor of Philosophy at Harvard University.

[2] J. Walther, *Das Gesetz der Wüstenbildung*, 2d ed., p. 174.

[3] William Mackie, *Trans. Edin. Geol. Soc.*, VII (1898), No. LV.

[4] Franz von Hauer, *Die Geologie*, 1875.

[5] W. S. Shaler, *U.S.G.S. Monograph XXXIII*, 1899, pp. 50–55.

[6] G. R. Mansfield, *Bul. Mus. Comp. Zoöl. Harvard*, XLIX (1906), 293–94.

of arkose are intermediate between these extremes, and that a moderately cool and arid climate such as would prevail at moderately high altitudes in the lee of high mountain ranges or in continental interiors would more probably be suitable. The present paper is an attempt to delimit the significance of arkose.

The fundamental conditions essential for the formation of arkose[1] are: (*a*) a granitic terrane, (*b*) conditions favorable to the disintegration of the granite or gneiss with but slight accompanying decomposition, and (*c*) conditions favorable to the erosion and deposition of the débris of disintegration with merely slight loss of the feldspar. In the investigation of the regions which today can supply débris of disintegration for the formation of arkose (Figs. 1 and 2), it was found that disintegration is much more widespread than is perhaps usually realized, and that it takes place in marked amounts under practically all the conditions under which a granitic terrane is exposed (see Table I, a list of the occurrences of disintegration which have been observed by the writer, or which he has been able to find described in the literature, together with a tabular view of the conditions under which the disintegration is taking place). The investigation of the conditions under which the disintegrated material could be eroded and deposited as arkose seems to show that in some cases the conditions favorable to the disintegration are likewise favorable to contemporaneous erosion and deposition of the disintegrated material as arkose, as, for instance, in desert regions, and that in other cases erosion can take place only after some change of conditions, as, for example, a change from the conditions of a moist temperate climate to those of a semi-arid climate. In yet other cases, erosion may take place contemporaneously with disintegration but be followed by decom-

[1] Arkose by original definition and according to most general usage is a rock formed of the relatively undecomposed débris of granite or of rods of granitic mineralogical composition. It may be thought, however, that the original definition should be extended to cover feldspathic clastics derived from the disintegration of syenites, diorites, gabbros. Feldspathic clastics of this type, however, should be rare, since there are practically no purely syenitic, dioritic, or gabbroic terranes, and since the plagioclase feldspar of the diorites and gabbros is more or less readily decomposed. No specimen of this type of feldspathic clastic has been seen by the writer, and only one or two reputed occurrences are reported in the literature.

LOCALITY	LAT.	LONG.	TOPOGRAPHY	ELEVATION	SITUATION OF DISINTEGRATION	DEPTH INTEGR
S.E. Ireland	53 N.	7 W.	Mature to old	Under 2,000 ft.		
Dartmoor, England	51 N.	4 W.	Old	1,500 ft.	General	6 to 1
Fores, France	45 N.	4 E.	Old	1,500 ft.	General	10 to 3
Plateau Central, France	46 N.	3 E.				
Morvan, France	47 N.	4 E.	Old	1,500 ft.	General	5 to 2
Hohkönigsburg, Vosges Mts., Alsace	48 N.	7 E.	Mature	1,500 ft.	General	8 to 2
Heidelberg Sheet	49 N.	9 E.	Mature	800 ft.	General	5 to 1
Adlersberg, Thüringerwald	51 N.	11 E.	Late maturity	2,000 ft.		5 to 8
Grimsel Pass, Alps	47 N.	8 E.	Young, glaciated mountains	6,500 ft.	Only valley seen	Superfic
Mer-de-Glace, Alps	46 N.	7 E.	Surface of alpine glacier	5,500 ft.	Surface	Superfic
Aswan, Egypt	24 N.	32 E.	Shallow young valley	400 ft.	General	Superfic
Pyramids of Gizeh, Egypt	30 N.	31 E.	Pyramids on a plateau	Less than 400 ft.	Surface of the pyramids	2/3 cm.
Sinai	30 N.	34 E.	Rugged		Valley sides	Partly s
Bushmanland, S. Africa	30 S.	20 E.				Superfici
Himalayas	34 N.	76 E.	Young, mountainous	Above 14,000 ft.	Exposed surfaces	Superfici
Ceylon	8 N.	80 E.	Mountainous		General	Few feet
Lung-wang-shan, China	41 N.	124 E.	Mountainous		Rolling valley in mountains	"Tiefgre
Around Inland Sea, Japan	38 N.	138 E.	High coast hills		General	
Mt. Chocorua, N.H.	44 N.	71 W.	Mature, mountainous	3,500 ft.	Summit and flanks of mountain	Mostly s
Jackson, N.H.	44 N.	71 W.	Mature, mountainous	700 ft.	Valley	5 ft. plus
Rockport, Mass.	43 N.	71 W.	Glaciated peneplain	100 ft.	Chiefly shown in glacial boulders	Superfici
Pikesville, Md.	39 N.	77 W.	Old	400 ft.	Surface generally	30 ft. pl
Washington, D.C.	39 N.	77 W.	Old	50 ft.	Surface generally	20 to 80
Richmond, Va.	37 N.	77 W.	Old	50 ft.	Surface generally	10 ft. plu
Georgia	34 N.	84 W.	Old	1,200 ft.	Surface generally	Incipient (aroun
Iron Mt., Mo.	37 N.	91 W.	Old	1,200 ft.	Surface generally	20–80 ft.
Mt. Stuart, Wash.	47 N.	121 W.	Ruggedly mountainous	9,470 ft.	Summit and exposed portions of flanks	Superfici
Wasatch, Utah	40 N.	111 W.	Ruggedly mountainous	6,000 ft.	Oldest moraine at base of range	20 ft.
Butte, Mont.	46 N.	112 W.	Rugged maturity	6,000 ft.	General	20 ft. plu
Pike's Peak, Colo.	39 N.	105 W.	Monadnock and peneplain	9,000 ft. 14,000 ft.	Summit and plateau	30 ft. in ficial in
Globe District, Arizona	34 N.	111 W.	Rugged maturity	6,000 ft.		Superfici
California: Sierra Nevada, Sierra Madre	34 N.	119 W.	Ruggedly mountainous	Above 6,000 ft.	Higher slopes	
Lower California	29 N. 31 N.	115 W.	Mountainous			
Valparaiso, Chile	33 S.	72 W.	Rugged	Less than 1,000 ft.	On ridge	
Sao Francisco, Brazil	9 S.	40 W.				100 ft. to 60 ft. ave

TABLE I

TABULAR VIEW OF THE OCCURRENCES OF DISINTEGRATION AND OF THE CONDITIONS UNDER WHICH THE DISINTEGRATION IS TAKING PL

SITUATION OF DISINTEGRATION	DEPTH TO WHICH DISINTEGRATION EXTENDS	DEPTH TO WHICH DECOMPOSITION EXTENDS	AMOUNT OF DECOMPOSITION SHOWN BY DISINTEGRATED ROCK	VEGETATIVE COVERING	SUMMER TEMPERATURE			
					Max.	Min.	Mean	
.....	.....	.....	.....	Grass and brush	.....	.....	57 F.	...
General	6 to 15 ft.	3 to 8 ft. Locally some hundreds of feet	Considerable	Heather and moss	68 F. (Mean max. July)	.....	60 F.	...
General	10 to 30 ft.	1 to 4 ft.	Noticeable though not very advanced	Grass and woods	95 F. (Mean extremes)	.....	64 F.	...
General	5 to 25 ft.	1 to 4 ft.	Noticeable though not very advanced	Grass and woods	About the same			A
General	8 to 20 ft. plus	1 to 4 ft.	Noticeable though not very advanced	Forest	.....	.....	64 F.	...
General	5 to 10 ft.	1 ft.	Noticeable though not very advanced	Forest	.....	.....	64 F.	...
.....	5 to 8 ft.	1 to 2 ft.	Noticeable though not very advanced	Forest	.....	.....	.....	...
Only valley seen	Superficial	.....	Very slight	Light or none	(Rigi-Kulm)		39 F.	...
Surface	Superficial	.....	Very slight	None	.....	.....	.....	...
General	Superficial, locally 10 ft.	None	For the most part very slight	None	112 F. (Mean extremes)	72 F.	93 F.	9
Surface of the pyramids	2/3 cm.	.....	Very slight	None	104 F.	64 F.	82 F.	7
Valley sides	Partly superficial	.....	Very slight	None	.....	.....	.....	...
.....	Superficial	.....	Very slight	None or very light	.....	.....	51 F. (Coldest month)	8 (W m m
Exposed surfaces	Superficial	.....	Very slight	None	.....	.....	.....	...
General	Few feet	Slight	.....	Forest	.....	.....	82 F.	...
Rolling valley in mountains	"Tiefgreifend"	Slight	.....	None	.....	.....	75 F.	...
General	.....	Slight	Very slight	Light forest	.....	.....	75 F.	...
Summit and flanks of mountain	Mostly superficial	.....	Very slight	Mostly none; some forest	.....	.....	.....	...
Valley	5 ft. plus	Slight	Noticeable though slight	Forest and grass	.....	.....	.....	...
Chiefly shown in glacial boulders	Superficial	.....	Noticeable though slight	Lichens	100 F. (For Boston)	45 F.	65 F.	7
Surface generally	30 ft. plus and minus	15 ft.	.....	Grass and forest	See Washington			...
Surface generally	20 to 80 ft.	Considerable	Considerable; at surface complete	Grass and forest	104 F.	36 F.	75 F.	7
Surface generally	10 ft. plus	5 ft. plus	Considerable; at surface complete	Grass and forest	See Washington			...
Surface generally	Incipient decay to 350 ft. (around Atlanta)	95 ft.	Considerable; at surface complete	Grass and forest	100 F.	55 F.	75 F.	73 (Fo lar
Surface generally	20–80 ft.	20 to 80 ft.	Considerable; at surface complete	.....	105 F.	45 F.	75 F.	70
Summit and exposed portions of flanks	Superficial	.....	Slight	Light	.....	.....	.....	...
Oldest moraine at base of range	20 ft.	Slight	Slight	Light	94 F.	33 F.	60 F.	...
General	20 ft. plus and minus	Slight	Slight	Light	94 F.	33 F.	60 F.	58
Summit and plateau	30 ft. in places; superficial in others	Slight	Slight	Light	.....	.....	37 F.	...
.....	Superficial	Slight	Slight	Grass and woods and light	117 F.	64 F.	90 F.	80
Higher slopes	.....	Slight	Slight	Light	.....	.....	.....	...
.....	.....	Slight	Slight	Light	.....	.....	.....	...
On ridge	.....	.....	Slight	Light	80 F. (Mean extremes)	44 F.	52 F.	...
.....	100 ft. to 300 ft. 60 ft. average	.....	Noticeable; at surface complete	.....	88 F.	72 F.	76 F.	...

MPERATURE		WINTER TEMPERATURE			RAINFALL			REMARKS
					Yearly	Monthly		
in.	Mean	Max.	Min.	Mean		Summer	Winter	
....	57 F.	.....	.....	.....	50 in.	4 in.	5 in.	
....	60 F.	.....	38 F. (Mean min. Jan.)	43 F.	60 to 80 in.	4 in.	5 in.	Medium-grained granite
....	64 F.	.....	7 F.	36 F.	32 in.	4 in.	3 in.	Coarse porphyritic granite; fine-grained granite not affected
he same		About the same as above			.....	.....	.....	Coarse and porphyritic granites; fine-grained granite not affected
....	64 F.	.....	.....	34 F.	70 in.	.....	.....	Coarse, porphyritic granite
....	64 F.	.....	.....	34 F.	60 in.	.....	.....	Coarse, porphyritic granite
....	.....	.....	2 F.	32 F.	.....	.....	.....	Medium-grained granite
)	39 F.	.....	.....	.....	.....	.....	.....	Medium-grained gneissic granite
....	.....	.....	.....	.....	.....	.....	.....	Medium-grained gneissic granite
F.	93 F.	90 F.	45 F.	62 F.	0	0	0	Coarse, porphyritic, biotite granite
xtremes) F.	82 F.	75 F.	39 F.	55 F.	1.5 in.	0	0.3 in.	Coarse, porphyritic, biotite granite
....	.....	.....	.....	.....	Less than 10 in.	.....	.....	
....	51 F. (Coldest month)	82 F. (Warmest month mean)	.....	.....	Less than 10 in.			
....	.....	.....	.....	.....	.....	.....	.....	
....	82 F.	.....	.....	80 F.	Over 50 in.	⅔ in June–July ⅓ in Oct.–Nov.		
....	75 F.	.....	.....	10 F.	30 in.	.....	.....	
....	75 F.	.....	.....	32 F.	85 in.	7 in.	9 in.	
....	.....	.....	.....	.....	.....	.....	.....	Medium-grained pyroxene granite
....	.....	.....	.....	.....	.....	.....	.....	Medium-grained, with a slight amount of biotite
F.	65 F.	70 F.	−13 F. (For Boston)	65 F.	45 in.	3 to 4 in.	3 to 4 in.	Medium- to coarse-grained granite; hornblende granite
nington		.....	.....	.....	.....	.....	.....	Fine-grained biotite granite
F.	75 F.	78 F.	−15 F.	34 F.	41 in.	3 to 4 in.	3 in.	Moderately fine mica granite
nington		.....	.....	.....	.....	.....	.....	Medium-grained mica granite
F.	75 F.	73 F. (For Atlanta)	−8 F.	44 F.	49 in.	3 to 4 in.	5 in.	Fine- to medium-grained, porphyritic mica granite
F.	75 F.	76 F.	45 F.	74 F.	40 in.	4 in	2 to 2.5 in.	
....	.....	.....	.....	.....	.....	.....	.....	Medium-grained granodiorite
F.	60 F.	.....	.....	.....	.....	.....	.....	
F.	60 F.	58 F.	−29 F.	24 F.	13 in.	1 in.	0.8 in.	Medium to coarse-grained mica, hornblende, quartz monzonite
....	37 F.	.....	.....	6 F.	30 in.	1.5 to 4 in.	1.2 to 2 in.	Coarse to coarse and porphyritic granite
F.	90 F.	80 F.	22 F.	50 F.	17 in.	4 in.	.....	
....	.....	.....	.....	.....	Very light	.....	.....	Granodiorite
....	.....	.....	.....	.....	Very light	.....	.....	Granodiorite
F.	52 F.	.....	.....	62 F.	29 in.,	⅓ in June and July		Fe-bearing minerals decomposed
xtremes) F.	76 F.	.....	.....	82 F.	12 in.	0 in.	1 to 2 in.	

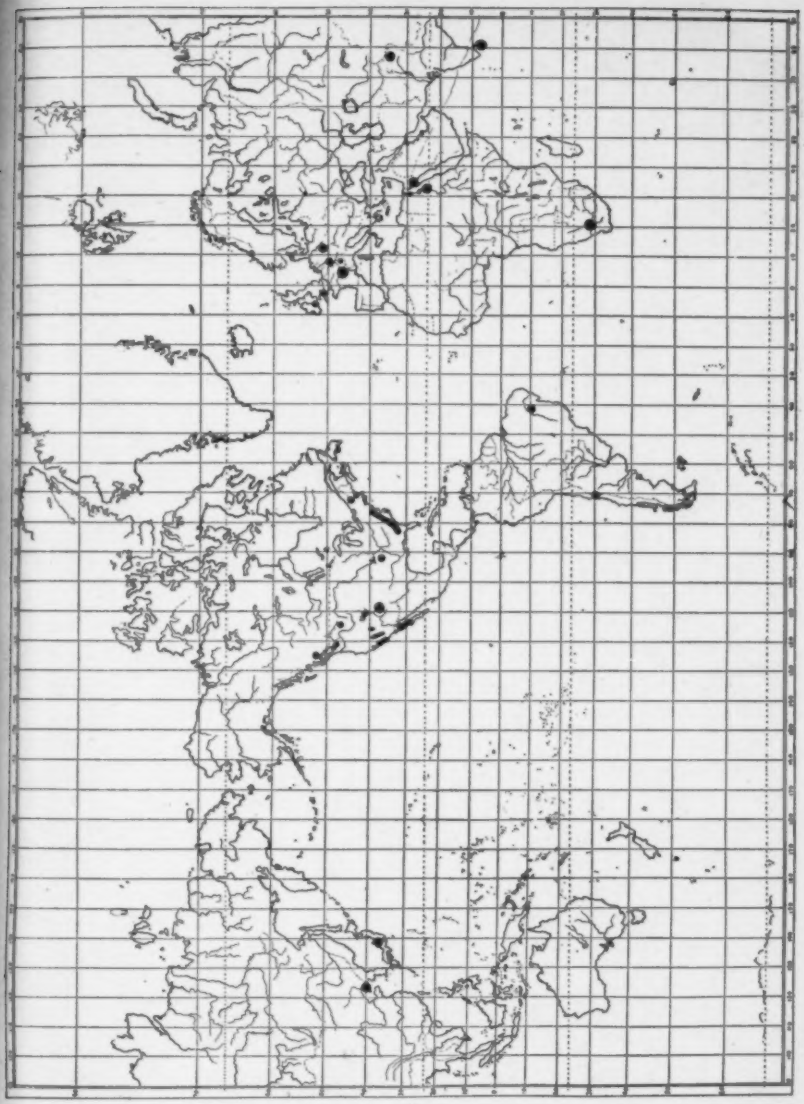

FIG. 1.—Distribution of the occurrences of marked granular disintegration as reported in the literature or observed by the writer.

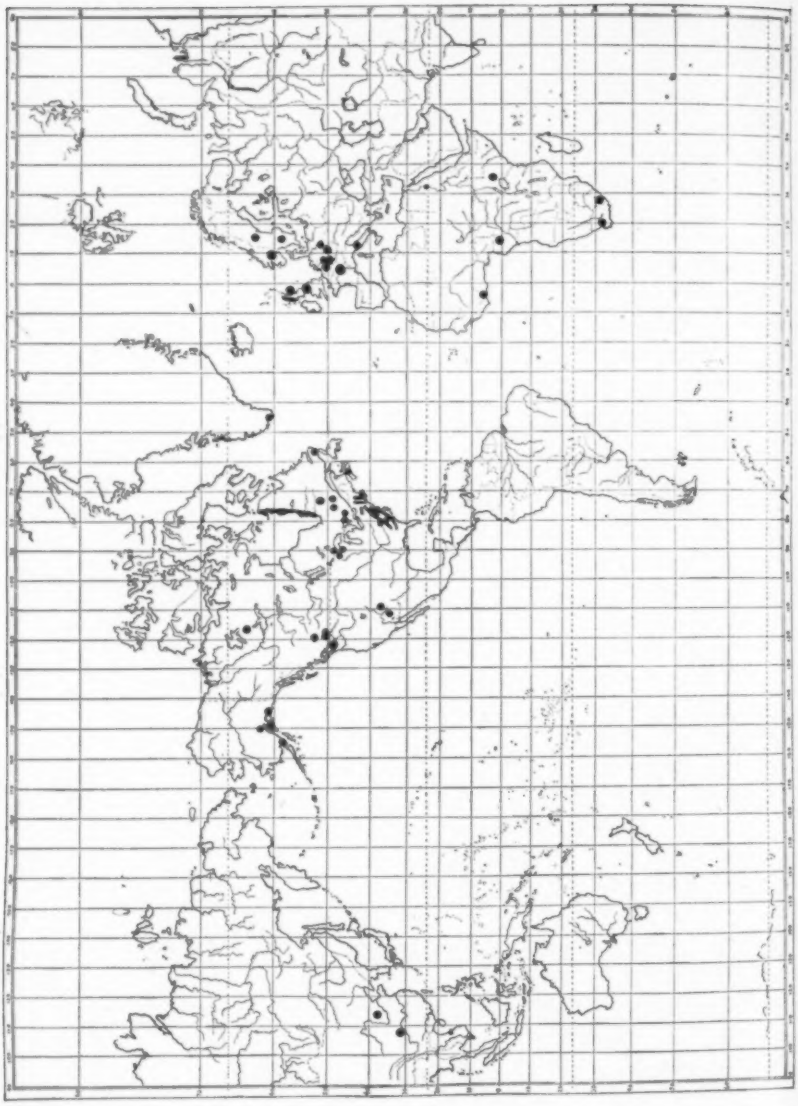

FIG. 2.—Occurrence of arkose deposits as reported in the literature or observed by the writer.

position of the feldspar, with the consequent loss of the material as a possible source of arkose. It was therefore found impossible to limit the significance of arkose to significance of any one or two special sets of conditions. The arkose deposits forming under the different conditions should expectedly be of certain characteristic types, which as a matter of fact agree with the types of arkose deposits as they are found (see Table II). The genetic classification of arkose deposits which appears in the following pages is therefore intended to embrace these various types of arkose deposits.

GENETIC CLASSIFICATION OF ARKOSE DEPOSITS

Arkose deposits may be divided broadly into two classes: (*a*) those formed directly through the effects of rigorous climatic conditions; and (*b*) those formed, at least indirectly, through the effects of moist and more temperate climatic conditions. The latter conditions allow much decomposition, which, however, commonly takes place at a slower rate than the disintegration. The arkose formed directly or indirectly under these conditions therefore has feldspars showing considerable decomposition, has in many cases a matrix of argillaceous material derived from the more easily decomposed grains of feldspar and other silicates, and is associated with beds of argillaceous material derived from the totally decomposed portions of the rock. The former conditions are unfavorable to decomposition, and the arkose deposits forming under them have comparatively unaltered feldspars, have little or no argillaceous matrix, and are not associated to any great extent with argillaceous beds. The distinction, however, is not absolute. At Aswan, Egypt, in a region in which no rain is recorded over a period of many years, the disintegrated granite in some places shows marked decomposition, and the feldspar of modern arkose deposits in the beds of the wet-weather streams of the region is deeply decomposed. In regions of moist, temperate climate it is not uncommon, on the other hand, to find below the zone of complete disintegration a zone of rock which to the eye seems fresh but which crumbles readily under blows from the hammer, and from this rock, within a region of moist, temperate climate, it would be possible for arkose with relatively fresh feldspar to form.

FIG. 2.—Occurrence of arkose deposits as reported in the literature or observed by the writer.

TABLE II

TABULAR VIEW OF THE OCCURENCE, CHARACTER, AND ASSOCIATIONS OF THE ARKOSE DEPOSITS KNOWN TO THE WRITER THROUGH THE LITERATURE OR THROUGH PERSONAL OBSERVATION

Formation and Region	Section	Character of Arkose	Remarks
	NORTH AMERICA		
	PRE-CAMBRIAN		
Hudson Bay (east coast)	Red sandstone and argillite and greywacke	More or less rounded grains and pebbles of quartz and feldspar	Arkose, coarse at base, grading upward
	600 ft. Arkose and greywacke		
	1,000 ft. Arkose		
Quebec: Nottaway River, St. Michel, Ranges III, X, XI	With dolomite, quartzite, conglomerate, and greywacke	More or less angular grains of orthoclase quartz and plagioclase	
Copper Cliff arkose, Sudbury, Ont.	Quartzite Greywacke Arkose	Felsitic-looking, interlocking grains, quartz and feldspars	Greywacke well stratified Arkose with little or no stratification
Loraine arkose, Cobalt, Ont.	900 ft. Quartzite Arkose Granite		Transition both into quartzite and into the granite
Temiscaming arkose, Nipissing District, Ont.	Arkose Granite	Quartzose and sericitic	Arkose grades into the granite
French River Quad., Ont.	With greywacke, quartzite, dolomite, agglomerate	In heavy bands	Possibly not arkose but tuff
Arkose, quartz slate, Penokee District, Lake Superior	Quartzite Arkose	Quartz, feldspars, mica and fine matrix	Arkose one phase of the quartz slate
Oak Portage	Arkose Sagana granite	Angular quartz and decayed feldspar in fine matrix	
Amnicon Formation, St. Louis River, Wis.	730 ft. Red shale, grits, sandstone and conglomerate, and arkose	Grains angular, poorly assorted	Three out of forty-five beds are arkose. Mud-cracks, raindrop prints, cross-bedding

Orienta sandstone, Wisconsin	1,500 ft. White and red sandstone, brownstone, white and pink sandstone 1,800 ft. Brown, red, and white sandstone, grading into arkose	Quartzose argillaceous	Mud-cracks, raindrop prints, cross-bedding
Belt Formation, Albert Canyon, B.C.	Limestone and argillite Quartzite Arkose Granite	Metamorphosed	Arkose is really a subordinate basal phase of the quartzite
Hotauto conglomerate, Shinumo Quad., Colo.	Limestone 0.6 ft. Arkose conglomerate and arkose argillite Quartz diorite		Unsorted
CAMBRIAN			
Eastern United States: Snowbird Formation, North Carolina	The base of Cambrian arkosic Georgia to Vermont 300–2,500 ft. Conglomerate with arkosic matrix 900–1,500 ft. Slate, greywacke, and feldspathic sandstone and limestone 350–5,000 ft. Quartzite with arkose and conglomerate Granite and gneiss	Moderately rounded quartz and feldspars in a fine-grained quartz-sericite matrix	The arkose is the basal of the quartzite
Hardistonville quartzite, New Jersey	Limestone Quartzite and arkose Granite and limestone	Moderately rounded quartz and feldspar in fine matrix	Arkose a phase of the quartzite
Vermont Formation, Massachusetts and Vermont	Limestone Quartzite Arkose conglomerate Granite and gneiss	Metamorphic	
Labrador: Straits of Belle Isle	Limestone 231 ft. Red and gray sandstone and arkose Arkosic conglomerate		

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
	CAMBRIAN—*Continued*		
Reagan Sandstone, Oklahoma	370 ft. Grit, sand with green sand, and clay	Arkose, coarse	
	30 ft. Arkose and quartzite		
Bolsa Quartzite, Bisbee, Ariz.	Granite and porphyry		
	Quartzite with arkosic matrix and phases		
	Granite and gneiss		
	SILURIAN		
Littleton, N.H.	150–500 ft. Dev. argillite	Basal arkose, granitic in appearance, feldspars and quartz in fine matrix	Basal arkose grades into the granite
	200–300 ft. Arkose	Upper arkose finer, more uniform, becomes quartzitic at top	Faint stratification
	200 ft. Limestone and slate		
	Limestone		
	2–80 ft. Arkose and quartzite		
	Granite-gneiss		
	DEVONIAN		
Igaliko sandstone, Greenland	Sandstone	Granitic in appearance	The arkose is a basal phase of the sandstone
	30–40 ft. Reddish and greenish arkose		
	Granite		
	CARBONIFEROUS		
Narraganset Basin	> 100 ft. Sandstone and shale, arkose and coal and conglomerate	Basal arkose, sometimes granitic, more often quartzose	Locally arkose grades into granite—massive or much cross-bedded — interbedded with the red shale, which has raindrop prints and sun-baked surfaces
	< 100 ft. Red shale	Fine matrix—coarse	
	< 100 ft. Arkose	Upper arkose fine-grained quartzose with fine matrix, both gray in color	
	Granite		

Rockwell Formation, Meadow Branch Mts., W.Va.	540 ft.	Arkose, sandstone, and shale with thin coal beds	Coarse, gray	Arkose basal phase of the Carboniferous
Myers Shale, Meadow Branch Mts., W.Va.	60 ft.	Red shale	Coarse, gritty, reddish-gray	Arkose cross-bedded
Horton Series, Nova Scotia		Arkose Arkose Granite and sediments	Medium and fine-grained, granitic in appearance, micaceous gray	Arkose with red shale intercalations carrying plant-fossils
		PERMIAN		
Cutler Formation, Colo.	1,500 ft. (total) 215 ft. (arkose)	Reddish Sandstones Arkose, grits, conglomerates, shale, and limestone	Quartzose and reddish	Part of the "Red Beds." Cross-bedding common
Fountain Formation, Colo.	500–1,500 ft.	Rough arkose grading into conglomerate, shale, and sandstone—all red	Coarse, rough, reddish	Part of the "Red Beds." Cross-bedding common
		TRIASSIC		
Sugar Loaf Arkose, Connecticut River, Mass. and Conn.		Sandstone Shale Arkosic sandstones and conglomerate with shale—base arkose Granite and gneiss	All rocks reddish Arkose varies from arkose conglomerate to granitic arkose and to arkosic grits Matrix of argillaceous material	All beds but shale much cross-bedded. Shale with mud-cracks, raindrop prints, reptile tracks, etc.
Stockton Arkose, N.Y., N.J., Md.	1,800–3,600 ft. 2,300–3,100 ft.	Argillite Reddish and yellowish to gray sandstone with some red shale and arkose and conglomerate at the base	Same as Sugarloaf arkose	Same as Sugarloaf arkose Arkose in thick beds or lenses

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
	TRIASSIC—*Continued*		
Tackahoe Group, Richmond Coal Basin, Va.	500 ft. Coarse sandstone (often feldspathic) 2,000 ft. Black shale with gray sandstone 500 ft. Coal, black shales, feldspathic sandstones 0–300 ft. Sandstones, shale Arkose Granite	Granitic in appearance Angular grains quartz and feldspars in fine-grained matrix Upper arkose reddish Main arkose gray	Arkose occurs not only at base but in beds at nearly all horizons. Cross-bedding common
	JURASSIC		
Skwenta Series, Alaska	Tuffs, slates, and arkose	Fine-grained, dark-green, massive	
Terra-cotta Series, Alaska	Impure limestones, slates, and diorite-arkose		
Naknek Series, Alaska	Arkose and conglomerate	Coarse to fine, hard and massive, in thick beds	Marine fossils in the arkose
	COMANCHEAN		
Patuxent Formation, Atlantic Coastal Plain	350 ft. Sand, arkose, and clay; granite	Decomposed	Fossil plants present
	CRETACEOUS		
Tordrillo Series, Alaska	Black and carbonaceous shales with limestone, sandstone, and arkose		Plant remains in the arkose and in the shales
Holiknuk Series, Alaska	Alternating sandstone and limestone, shale and arkose	Shale and arkose carbonaceous locally	Plant remains and ripple-marks in the shale and the arkose
Oklune Series, Orca Series, Alaska	Very similar to the preceding		

Paysaten arkose, Mt. Hozomeen, B.C.	3,000 ft. Gray to black argillite 7,100 ft. Gray to green feldspathic sandstone with black argillite lenses 1,400 ft. Coarse conglomerate 300 ft. Argillite 3,500 ft. Green feldspathic sandstone 200 ft. Coarse conglomerate 1,500 ft. Gray to green feldspathic sandstone 100 ft. Conglomerate 1,100 ft. Feldspathic sandstone 600 ft. Red argillite and sandstone 10,000 ft. Massive arkose Volcanic agglomerate Granodiorite	Light-gray, medium-grained, granitic in appearance; angular grains of feldspars and quartz with no matrix; feldspar fresher than in most arkose	Arkose shows little variation in character and little stratification. Plant fossils at two horizons
	EOCENE AND OLIGOCENE		
Kettle River Formation, Phoenix, B.C.	Conglomerate, coarse and fine sandstone, carbonaceous shales, and arkose	Quartzose	
Swank Formation, Yakima Valley, Washington	3,500–5,000 ft. Arkose, carbonaceous shales, sandstone with arkose or conglomerate at the base		
Puget Formation, Puget Sound, Washington	5,500 ft. Sandstone and arkose with shale and coal beds	Arkose variable in different layers—some granitic in appearance, some grading into sandstone, bluish-gray in color	All the beds carbonaceous Formation is thinly bedded and with much cross-bedding
Kenai Formation, Alaska	Sandstone, shale, and conglomerate, with coal seams Arkose Quartz diorite	Arkose in part granitic in appearance	

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
	EOCENE AND OLIGOCENE—*Continued*		
Controller Bay region	2,500 ft. Shale and sandstone with coal, arkose, and conglomerate		The different rocks are in monotonous repetition
	EUROPE		
	PRE-CAMBRIAN		
Torridonian sandstone, Scotland	3,000–4,000 ft. Red and gray sandstone and flags, dark shales 5,000–8,000 ft. Red arkose with rare red shales 500 ft. Red sandstone and mudstone with dark shale breccia at base 7,200 ft. In Skye, gray, and buff arkose Lewisian gneiss	Upper arkose (Applecross) granitic in appearance, composed of moderately rounded to well-rounded grains of fairly fresh feldspar and quartz with no matrix	Arkose massively bedded and almost always cross-bedded Dreikantes and raindrop prints occasionally present The arkose is very uniform throughout
Sparagmite, Norway	>5,000 ft. Red arkose and sandstone with breccia, quartzite, and conglomerate	Subangular to moderately well-rounded grains of fresh feldspar and quartz	Similar to Torredonian arkose
Jotnian, Angermanland	White or yellow quartzite with brown shale and with conglomerate Arkose Granite		
	CAMBRIAN		
Scandinavia	Sandstone grading into arkose at base Arckaean crystallines		

DEVONIAN				
Gedinnian Formation, Ardennes and Eifel districts	10–300 ft.	Shales and sandstones Arkose and sandstone, thin conglomerate	Sericite meta-arkose Quartz grains partially rounded	Bedding even Arkose in beds 3–5 ft. thick. Associated beds with marine fossils
Old Red sandstone, Great Britain			Some granitic in appearance, some conglomeratic Color, pink to red Feldspar fresh	Several phases of the Lower Old Red Sandstone would seem to be arkose
CARBONIFEROUS				
Berghaupten, Baden	300 ft.	Interbedded arkose, coal, shale, and conglomerate Granite and gneiss	Arkose granitic in appearance, often coarse, sometimes fine, massive, carbonaceous	Coarse cross-bedding common Carbonized plant remains in arkose
Baden-Baden, Baden Hinterohlsbach Basin Openau, Baden		Small basin much similar to the preceding		
Hohengeroldseck, Baden	130 ft.	Arkose with coal and sandstone		
	90 ft.	Brown micaceous sandstone		
		Coarse arkose		
		Gneiss		
Relsen Coal Basin		Red and white sandy clay		
		Arkose		
		Clay		
		Sandstone		
		Black argillite		
		Arkose		
		Argillite		
Braunau and Kalna Formations Riesengebirge Kladrio-Rakonitzer Coal Basin		Arkose, reddish sandstone and shale and marl Base of coal measures sandy slate and arkose		

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
	CARBONIFEROUS—*Continued*		
Laach, Vosges Mts.	210 ft. Grayish arkose with fine conglomerate 6 ft. Coarse conglomerate 18 ft. Small bed of coal Grayish arkose Gneiss	In part granitic in appearance; subangular grains quartz and much kaolinized feldspar in fine matrix	Carbonized plant remains in the arkose
Erlenbach and Weiler, Vosges Mts.	Arkose of similar character and relations		Thought to be a delta deposit
Lower Rotliegendes and Upper Carboniferous, Ottweiler, Rhine Province	Conglomerate and feldspathic sandstone Black shale and yellow, fine-grained sandstone Shale and sandstone with coarse conglomerate Gray sandstone and shale with a little coal Reddish arkose, shale, and feldspathic sandstone Gray shale Red sandstone and shale	Quartzose, grains subangular, matrix about 20 per cent	Stratification rough; beds roughly 3 ft. thick, cross-bedding common Very similar to arkose of Triassic of Massachusetts, New York, and New Jersey
Yorkshire Coal Field, England	In coal measures	Granitic in appearance; color bluish or grayish	Irregularly bedded; much cross-bedding
Flint Ruthin and Mold, England		Gray in color; granitic in appearance	
	ROTLIEGENDES		
Cuseler and Tholeyer Beds, Saar and Nahe District, Germany	Reddish feldspathic sandstone, arkose, shale, and conglomerate with rare gray shale and limestone	Quartzose; feldspar now decomposed	Roughly bedded; cross-bedding common

Tholeyer Beds, Mainz Basin, Germany		Red arkose with red shale, sandstone, mudstone, and marl	Quartzose; feldspar now completely decomposed	Arkose is in massive, even layers, with rare cross-bedding Lithologically very similar to arkose of the Triassic of Massachusetts, Connecticut, New York, and New Jersey
Heidelberg, Germany		Tuffs Arkose and tuffs Granite	Coarse and granitic in appearance	
Baden-Baden, Germany		Red sandstone, shale conglomerate with arkose Black and variegated shale Arkose and variegated shale Granite		
Oppenau, Black Forest		Arkose with dark shales, sandstone, and conglomerate		
Lebach beds, Schramberg, Black Forest	100 ft.	Alternating gray arkose and shale		Plant impressions in the shale
Schöpfheim, Black Forest		Feldspathic sandstone with arkose and dolomite Reddish shales, mudstones Conglomerate, arkose, and sandstone	Quartzose, red feldspar now completely kaolinized	Stratification rather even, massive. Facetted pebbles possibly present
Trienbach beds, Vosges Mts.	90 ft. 60 ft. 60 ft.	Purple shale with arkose intercalations Gray arkose with shale Arkose with conglomerate granite, schist, or Erlenbach beds	In part very granitic in appearance	Plant fossils present
Kohlbachel beds, Vosges Mts.	540–600 ft.	Reddish arkose, shales, conglomerate, and breccia	Quartzose	The arkose is only a local phase of the sandstone

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
	ROTLIEGENDES—*Continued*		
Thuringia Forest	Conglomerate, shale, sandstone, arkose, and breccia Granite	Coarse, gray, with fine matrix	The arkose is a basal phase, but is not derived from the underlying granite
	TRIASSIC		
Morvan district, France	Limestone and gypsum 30 ft. Arkose and marl 90 ft. Arkose with clayey intercalations Granite	Quartzose and heavily silicified, constituent grains showing much rounding; fine-grained silicified matrix	Lower arkose in massive, even beds at the base, with thin shale beds toward the top with reptile tracks
Rémilly, near Dijon Aubenais, Ardecke Chessy, near Lyons	Somewhat similar arkose, possibly the equivalent of the preceding arkose		
Rhaetic beds Bunt Keuper beds Franconia	600 ft. Sandstone, grading into arkose in the Palatinate at Parkstein and vicinity 150 ft. Red argillite 60 ft. Sandstone, locally feldspathic Dolomitic arkose, limestone, reddish clay, and marl Sandstone, clay, marl, and arkose	Mostly very quartzose with or without much matrix	The deposits, especially of the arkose, are supposed by Thürach to be shore deposits
	TERTIARY ARKOSE		
Stampian Beds Sannoisian beds Limagne, France	Marls and limestone Arkoses, sandstones and marls, grits (Sandy clays, limestone and basal arkose in southern part of the basin only) Granite	Coarse to fine, in part very granitic in appearance, usually with more or less argillaceous matrix	Arkose is in more or less massive beds; rarely there is some cross-bedding

		Granite		
Basin of Lembron Basin of Forez France	Arkose deposits similar to the preceding and probably equivalent to them			
		ASIA		
Yang-Tzi Province	150 ft.	Tillite (Cambrian) Coarse sandstone and conglomerate Arkose and conglomerate Granite		
Wu-t'ai System		Pelites Psammites Arkose T'ai-shan gneiss	Much metamorphosed	
Alwar Formation, India		Quartzite with basal arkose		
Araveli Group, India		Gneiss, schist, and quartzite		The gneiss is believed by Oldham possibly to represent arkose
Bawar Formation, India		Limestone and carbonaceous shales Quartzite and arkose Granite	In parts granitic and very similar in appearance to the underlying granite	
Eocene beds, Upper Indus		Heterogeneous sandstones and conglomerates, possibly with some arkose		
		AFRICA		
Congo Series, Matjé's River, Cape Colony			Coarse, granitic in appearance, matrix of quartz and sericite	
Congo Series, French Hoek, Cape Colony		Limestone Arkose and feldspathic grits Conglomerate Granite	Granitic in appearance	Locally the arkose grades into the granite

TABLE II—*Continued*

Formation and Region	Section	Character of Arkose	Remarks
	AFRICA—*Continued*		
Nieuwerust Series, Cape Colony	Dark shale and sandstone Arkosic conglomerate with shale and sandstone Gneiss		
Black Reef Series, Cape Colony	Quartzite and slate Arkose and conglomerate Granite		
Gold Coast	Arkose with clayey and pebbly beds	Reddish grit with angular grains	
Carboniferous and Devonian, French Congo	Arkose, whitish sandstone and dolomitic layers Greenish and reddish shales and calcareous sandstones Arkose Crystalline schists		
Lake Rudolf, British East Africa	Grauwacke and arkose Crystalline schists	Reddish, quartzose with fine matrix	
Nubian sandstone	Argillaceous sandstone and conglomerate Arkose Granite	Very granitic in appearance	Faint stratification possibly present in upper part of the arkose; the arkose grades into the granite
	AUSTRALIA AND SOUTH AMERICA		
	No account of arkose either in Australia or in South America has come to the notice of the writer		

A. ARKOSE DEPOSITS FORMED ENTIRELY UNDER RIGOROUS CLIMATIC CONDITIONS

Feldspar showing merely slight decomposition.[1] Argillaceous material absent or present in minor amounts.[2]

1. *Deposits formed in desert regions.*—The deposits are massive, homogeneous, and in some cases of very large size. In desert regions, the disintegration takes place chiefly on outcrops directly exposed and not protected, as in moist temperate regions, by a mantle of vegetation. The débris of disintegration is easily eroded and the processes of erosion and disintegration and deposition of the eroded, disintegrated material as arkose can therefore take place contemporaneously, and can continue as long as the desert conditions persist and as long as the granitic terrane remains unburied. The size of an arkose deposit formed under such conditions will therefore depend chiefly on the size of the terrane of disintegration, the size of the basin of deposition, and the length of time the desert conditions prevail. The constancy of the conditions during the period of formation should be marked by a massiveness and homogeneity of the deposits.

a) Terrestrial: In deserts, wind action prevails the greater part of the time, but rare storms do occur and in the short space of their existence do an immense amount of work. Deposits of arkose formed in desert regions therefore are likely to be in part of eolian and in part of aqueous origin. The arkose shows in part the eolian characteristics of well-rounded sand grains, faceted pebbles, local lag-gravels, dune stratification, etc., and in part the ordinary characteristics of water action. In deposits of arkose forming in arid mountain regions, the greater part of the transportation of the disintegrated material may be by water action, during the rare cloudbursts, and by the streaming of the débris down the hill slopes under gravity. The constituent grains in this case are subangular, and quartz and feldspar grains should be present in about the same proportions as in the original granite or gneiss, since the amount of

[1] At the time of formation of the arkose. Subsequent exposure may produce complete decomposition.

[2] The possibility of the presence of exotic material brought in by a river whose headwaters lie in a temperate or tropical region should not be forgotten.

transportation undergone should not be sufficient to cause marked comminution and loss of the feldspar. The deposits as a whole should be rather massive, but with cut-and-fill stratification rather common, and with considerable intercalation of coarse block débris toward the sides of the valleys.

An example of this type of deposit is found in the Applecross group of the Torridonian sandstone, a pre-Cambrian formation extensively developed in the Northwest Highlands of Scotland. The ideal section of the Torridonian sandstone is given by the Geological Survey[1] as shown in Table III. The Applecross group

TABLE III

Groups	Thickness	Composition	Chief Occurrence
3. Aultbea....	3,000–4,000 ft.	Sandstone, flags, dark and black shales, and calcareous bands passing down into chocolate and red sandstones, and gray micaceous flags with parting of gray and green shale	Loch Ewe and Loch Broom
2. Applecross..	5,000–8,000 ft.	Chocolate and red arkose with pebbles of quartzite, quartz-schist (felsite, jasper, etc.), and occasional red and chocolate shales	Cape Wrath to Skye
2. Diabaig....	500 ft. in Gairloch; 7,000 ft. in Skye	At top, fine red sandstone with red mudstone and gray shale; at base, coarse breccia of Lewisian gneiss. In Skye, gray and buff arkose in great thickness	Assynt to Skye

is a formation composed of massive arkose of very uniform character (Fig. 3), marked off by thin intercalations of fine quartzitic and shaly sandstone into persistent layers of rather uniform thickness—in each case three, six, or ten feet or so. Although extremely massive in texture, the arkose shows most irregular stratification and almost invariably is strongly cross-bedded. Walther reports cross-bedding indicative of dune formation, and faceted pebbles. The lithologic character of the arkose may be seen from the accompanying photomicrograph. In the finer-grained phases, quartz composes a slightly greater proportion of the whole than in this medium-grained phase (quartz about 60 per cent and feldspar 40 per cent), and the grains

[1] B. N. Peach, J. Horne, and others, "The Geologic Structure of the Northwest Highlands of Scotland," *Mem. Geol. Surv. Great Britain*, 1907.

show a slightly greater degree of rounding. It is notable that the predominant feldspar of the arkose, microcline, does not occur in the underlying terrane. Where the arkose rests directly on the mountainous topography of the underlying terrane, the arkose basally becomes a coarse breccia. One of the most striking features of this formation, with the exception of this basal portion, is its uniformity throughout its great thickness.

To this type of arkose deposit should be referred the following:

The Torridonian Arkose, pre-Cambrian of Scotland.

Arkose of the Sparagmite formation, pre-Cambrian of Scandinavia

Lower Old Red Sandstone, Scotland (in part)

Paysaten Arkose, Cretaceous, British Columbia–Washington

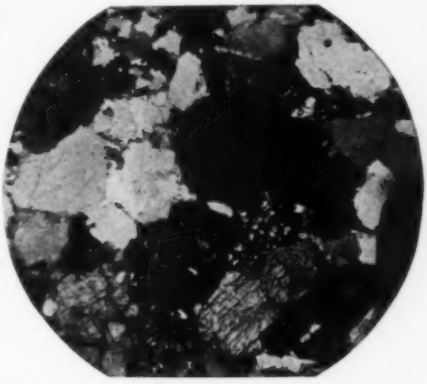

FIG. 3.—Photomicrograph of Terridonian arkose, Applecross, Scotland, showing the lack of matrix in a desert arkose. The rounding of the grains is rather obscured by secondary growth of the grains. Magnification, 15 diameters.

b) Marine: If marine conditions prevail adjacent to a granitic terrane in a desert region, marine arkose may form, having in part the characteristics of an eolian arkose. Some of the constituent grains in this case should show the rounded outlines of eolian sand grains. The deposits as a whole, however, should show the structure and stratification of marine sediments. To this type of deposit should be referred the arkose that is now forming along the east shore of the Gulf of California.

2. *High-altitude deposits.*—Local deposits, of small size and extent. The conditions of high altitude, according to Oldham and others, are peculiarly favorable to disintegration. Erosion of the disintegrated material takes place rapidly, with rapid deposition of it in many cases as arkose in local catchment basins of the intra-mountain valleys. As such a region is subject to general

degradation in the course of time, the deposits must be temporary in character, and usually of recent geologic age. They may be wholly or in part lacustrine, fluviatile, alluvial (cone or fan), landslide, or fluvioglacial. The stratification should be rather irregular, and the constituent grains should be angular to subangular.

To this type of deposit should be referred possibly some of the deposits of the Upper Indus Valley, although from the descriptions of the deposits it is not quite clear whether they are really arkosic or not.

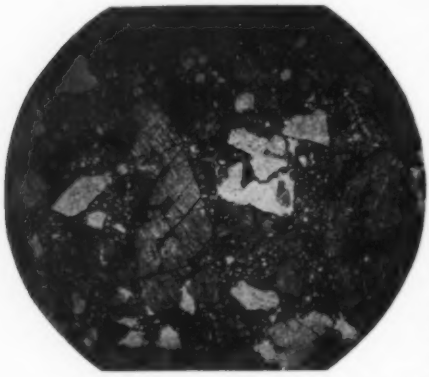

FIG. 4.—Photomicrograph of Pondville (Mass.) arkose, an arkose formed under moist temperate conditions, showing the quartz and feldspar grains in a fine-grained matrix of quartz and argillaceous material. Magnification, 15 diameters.

3. *Deposits of cold (high-latitude, subglacial) climate.*—In the high latitudes, the effects of disintegration are not pronounced, or at least they are not noted in the literature. "Disintegration" is reported many times, but in most cases it is clearly block disintegration that is meant, and in no case has the writer been able to make it out clearly to be granular disintegration. That the effects of the latter are not noticeable may be due in large part to the relatively recent glacial erosion of the products of the preglacial disintegration, or, in regions of considerable relief, it may be due in part to excessive block disintegration and erosion. As the temperature range is often great, and the lower part includes the critical point of freezing, and as, furthermore, hydration can take place at the surface during the summer and, in regions not too far north, at all times below the level of freezing, there would seem to be no theoretical reason why granular disintegration should not take place. Granitic and gneissic blocks exposed on the surface of glaciers in many cases show noticeable disintegration, although

the amount that takes place in this manner is slight. If disintegration takes place, the conditions would seem favorable to the erosion of the disintegrated material and its deposition in arkose deposits of small or moderate size, probably in association with glacial or fluvioglacial beds. To this type of deposit may possibly be referred some of the pre-Cambrian arkose of Canada.

B. DEPOSITS FORMED DIRECTLY OR INDIRECTLY THROUGH THE EFFECTS OF MOIST AND USUALLY TEMPERATURE CONDITIONS

Deposits of small or moderate size; the arkose commonly with a matrix of fine-grained argillaceous material and usually associated with argillaceous beds; feldspars commonly showing a moderate amount of decomposition (Fig. 4).

In the present regions of moist temperate climate, especially where the topography is in a mature or old-age stage of development, there is almost universally present a very considerable accumulation of disintegrated material which is available as a source of material for the formation of arkose. The following section, from the vicinity of Autun, France, in its essential features is characteristic of such regions as the granite terranes of Morvan, the Plateau Central, and Forez, France; the Vosges Mountains, the Odenwald, and the Thüringerwald, Germany; Dartmoor, England; the Piedmont belt and the Pike's Peak region, United States.

1 ft..... Mantle of vegetation; surface soil and subsoil of gritty brown clay with quartz and feldspar grains

6 ft..... Granitic sand and gravel, stained with limonite; feldspar showing considerable decomposition toward the surface, the amount decreasing with depth

2+*n* ft..... Granite more or less fresh on superficial examination, but crumbling under light blows of the hammer; depth difficult to estimate; fresh granite

The relative and absolute proportions of these zones vary greatly. The maximum depth to which disintegration was observed by the writer to have extended was 40 feet, at Royat (Puy-de-Dôme), France, and at Hohkönigsburg, Vosges Mountains. On Dartmoor and in the Piedmont belt decomposition is more in evidence than in France and, in the Piedmont belt especially, the zone of soil and

subsoil is much larger in proportion to the zone of disintegrated material. The rate of disintegration under the conditions of a moist temperate climate seems to be rather slow—in New England there has been since the Glacial Period disintegration sufficient barely to efface the glacial striae and polish on granitic and gneissic ledges—and the very considerable amounts of disintegrated material generally found in those regions are the result of slow accumulation under the protection of the mantle of vegetation. General erosion of this disintegrated material and its subsequent deposition as arkose can take place only when the mantle of vegetation is critically weakened or destroyed. When this has once happened and the mantle of disintegrated material has been swept away, a long time must elapse before considerable amounts of the disintegrated material can again accumulate. The arkose deposits formed from the accumulated débris of disintegration in a moist temperate climate will therefore be of small or moderate size. As the mantle of soil and completely decomposed rock is eroded at the same time as the mantle of disintegrated material, the arkose is commonly associated with mudstones and shales, and, as the disintegration is accompanied by considerable decomposition, the arkose itself is likely to contain much argillaceous material and to have feldspars showing noticeable decomposition. Since stream transportation of débris results in the rather rapid elimination of the feldspars, the arkose is likely to grade into quartzite.

The causes which might critically weaken or overcome the mantle of vegetation and result in the erosion of the accumulated products of disintegration are: introduction of arid or semi-arid conditions, introduction of subglacial or glacial conditions, a marked increase of rainfall, a marine transgression, deforestation by forest fire, and marked upwarping. A marked change of climatic conditions toward aridity in a region previously of moist temperate climate would necessarily result in a marked diminution of the vegetation and in the exposure of the underlying disintegrated material to erosion during the occasional storms. Glacial conditions might result either in the erosion of the disintegrated material by the ice itself or in the exposure of the disintegrated material to erosion through the destruction of the vegetation of the temperate

conditions without the introduction of an arctic flora sufficiently luxuriant to form anew the protective mantle of vegetation. A marked increase of the rainfall, it was suggested by Shaler, might be such that the streams would be competent to waste generally the land surface. A marine transgression would necessarily result in the working over of the materials of the regolith, irrespective of the luxuriance of the mantle of vegetation, and might easily result in the deposition of arkose. Forest fires are not uncommonly due to lightning and often are effective agents of deforestation. It would seem possible that a period of heavy rains following a severe forest fire might result in the general erosion of the mantle of disintegration. Upwarping of considerable amount would result in an increase of the stream gradients, in an increase or decrease of the rainfall, and in the lowering of the mean temperature. The total effect might possibly be conditions favorable to the general erosion of the mantle of disintegration. A very special cause is to be found in volcanic activity of the explosive type, which not uncommonly results in deforestation and desolation in limited local area. Of this type of deposit, in which the arkose should be associated with tuffs, there is at least one example, the Rotliegendes arkose north of Heidelberg, Germany.

In regions of youthful topography and considerable relief in a moist temperate climate, there would seem to be no reason why disintegration should not take place. That it is not seriously in evidence is probably due to the fact that it is masked by block disintegration and by rapid erosion. If it does take place, the débris that can be eroded at one time is of small amount and is lost through decomposition of the feldspars or through intermixture with the heterogeneous stream-borne sediment.

In tropical regions, decomposition commonly prevails over disintegration, but in two localities disintegration is reported as occurring with but slight accompanying decomposition. The débris in these cases, if eroded under normal conditions, would probably be lost through decomposition, but if eroded under the conditions of a marine transgression, or under the conditions of aridity, there would seem to be a strong possibility that a deposit of arkose might be formed. Except by means of a contained fauna or flora, such

deposits would probably be indistinguishable from the corresponding types of deposits of the temperate zone. No deposits have been recognized to be of this type.

1. *Terrestrial.*—(*a*) Deposits laid down under semi-arid conditions: Arkose reddish, composed of subangular iron-stained grains of quartz and partially decomposed feldspar deeply in an iron-stained matrix of fine-grained quartz and of argillaceous material.

When the moist temperate conditions give way to those of aridity, the mantle of vegetation, weakened by the change, is no longer able to protect the accumulated products of decomposition and disintegration, and during the occasional violent storms they are quickly eroded, to be deposited with rapidity usually in the near-by valleys and catchment basins. Owing to deposition from torrential streams, the materials of the mantle of disintegrated material are laid down in coarsely stratified banks and lenses of arkose, showing much foreset and cut-and-fill cross-bedding. The soil and mantle of completely decomposed rock are deposited, partially sorted, as cross-bedded, argillaceous sandstones and as more finely and evenly stratified gritty mudstones. As the temporary lakes dry up, these mud beds become sun-baked and glazed and cracked and may receive raindrop prints. Under the conditions of alternate wetness and dryness, there should be almost complete decomposition of organic matter and oxidation of the iron.

Deposits of this type are not rare, and a good example may be found in the Sugarloaf arkose of the Connecticut River Triassic. The formation occurs in what was possibly a Triassic basin, and consists essentially of an unordered alternation and repetition of gritty, argillaceous sandstones, conglomerates, arkose, and sandy and calcareous mudstones. There is a coarse, general stratification whose dip initially was apparently low. In the beds of mudstone, even, fine stratification is the rule, but cut-and-fill bedding is found in a few places. The coarser strata are strongly cross-bedded, mostly with the foreset type of bedding. Cut-and-fill bedding, however, is common. The mudstones show mud-cracks, raindrop prints, glazed surfaces, and reptile footprints. The arkose is found in banks and lenses, chiefly at or near the base, but also at

numerous higher horizons. It is composed of subangular grains of quartz and subangular grains and pebbles of feldspar in a fine-grained matrix of argillaceous material. The color of the whole formation is deep red, due to a heavy stain of ferric iron. Fossils are rare in the formation.

The following deposits are apparently of this type:

Arkose of the Amnicon formation, pre-Cambrian, Wisconsin

Sugarloaf arkose (Triassic), Connecticut River area, Massachusetts and Connecticut

Stockton arkose (Triassic), New York, New Jersey, Pennsylvania

Arkose of the Upper Carboniferous, Ottweiler, Rhine Province, Germany

Arkose of the Lower Rotliegendes, Rhine Province, Germany

Arkose of the Rotliegendes, Mainz Basin, Vosges Mountains and Black Forest, Germany

Arkose of the Old Red Sandstone, England

Arkose of the Cutler formation, Permian, Colorado(?)[1]

Arkose of the Fountain and Lower Wyoming formations (Permian), Colorado(?)[1]

(*b*) Deposits laid down under moist, chiefly temperate, conditions of climate: Arkose grayish, composed of subangular grains of quartz and of considerably decomposed feldspar in a matrix of fine-grained quartz and argillaceous material, in most cases carbonaceous, and in some cases carrying plant fossils; the arkose commonly associated with coal deposits.

The causes of a general erosion of the regolith in a region of moist temperate climate are not completely evident. The suggestion of the introduction of subglacial conditions as a possible cause seems not well founded, since the several glacial epochs of the Pleistocene do not seem to have caused a general erosion of the regolith of the Piedmont belt to the south of the glaciated area. It would seem reasonable to expect, furthermore, that the effect of the change on the mantle of vegetation would be a replacement of the temperate by arctic flora. The suggestion that a marked increase in the amount of the rainfall might be a sufficient cause would likewise seem not well founded, as an increase in the rainfall characteristically results in more luxuriant vegetation, with a consequent increase in the protective power of the mantle of vegetation.

[1] Commonly considered marine, but apparently very like the Newark beds of the Connecticut River and the New York-New Jersey Triassic areas.

Forest fires are another possible cause. They are very commonly due to natural causes and often are effective agents of deforestation. It would seem possible that a period of heavy rains following a severe forest fire might easily result in the general erosion of the regolith. Upwarping of considerable amount, with the consequent increase of stream gradients and lowering of the mean temperature, if associated with decrease in the amount of the rainfall, might possibly result in the general erosion of the regolith.

While these causes are thus in doubt, the fact of the formation of deposits under these general conditions seems to be indubitable. There is a characteristic type of arkose deposit which is usually associated with carboniferous beds or coal, which is itself carbonaceous or may even carry carbonized plant remains, and which therefore must have formed under moist climatic conditions. As the feldspar shows much decomposition, as there is an argillaceous matrix, and as the quartz and feldspar grains are distinctly angular to subangular, the constituent materials of the arkose would seem to have been derived from the débris of disintegration under moist temperate conditions. The arkose, commonly in part, is coarse and granitic in appearance and seems not to have been transported far from the point of origin of its constituent material, and in part usually is finer and less feldspathic, and seems to have been transported for a greater distance. Besides being associated with coal beds, the arkose is associated with conglomerates, impure sandstones, and silty mudstones. Cross-bedding is common, and many of the beds seem to be the result of rather rapid deposition. The color of this type of arkose is gray.

As an example of this type of deposit, there may be taken the arkose of the Richmond (Triassic) Coal Basin in Virginia. The lower portion of the section in the basin is as follows:[1]

Productive Coal Measures	500 ft.	Interstratified beds of bituminous coal, black shale, feldspathic and micaceous sandstones
Lower Barren Beds	0–300 ft.	Sandstones and shales under the coal beds, often with arkose
Boscabel Bowlder Beds	0–50 ft.	Local deposits of bowlders of gneiss and granite

[1] N. S. Shaler and J. B. Woodworth, *U.S.G.S. Nineteenth Ann. Rept.*, Part II (1897–98), pp. 423–26.

The arkosic beds are best developed about the granitic masses of the eastern margin, but reappear from horizon to horizon with increasing marks of waterwear. The arkose of the basal horizons is granitic in appearance, and by the inexpert eye might not be distinguished from the granite. The arkose is gray in color and is composed of subangular grains of quartz and much decomposed feldspar in an argillaceous matrix of small amount. The arkose of the higher horizons is not so granitic in appearance, there is a somewhat lower content of feldspar, and the quartz and feldspar grains are slightly more rounded. Some of the associated shale beds are carbonaceous, and locally there are small intercalations in the arkose of carbonaceous silty material.

To this type of deposit there should probably be referred:

The Carboniferous arkose of the Narragansett Basin, Rhode Island and Massachusetts
The arkose of the Rockwell formation (Mississippian), Meadow Branch Mountains, West Virginia
The arkose of the Vosges Mountains, the Black Forest, and adjacent parts of Bavaria
The arkose of the Coal Measures of the Yorkshire Coal Field, England
The arkose of the Coal Measures of the Flint, Rhutin, and Mold districts, England
The arkose of the Richmond (Triassic) Coal Basin, Virginia
The arkose of the Corwin formation (Jurassic), Alaska
Comanchean arkose at the base of the Coastal Plain series, Maryland, Virginia, North Carolina
The arkose of the Swauk formation (Tertiary), Washington
The arkose of the Puget formation (Tertiary), Washington.
The arkose (Early Tertiary) of the Matanuska and Controller Bay regions, Alaska

c) Deposits formed under glacial conditions: If an ice sheet advances over a granitic terrane in which there is a mantle of disintegration, it would seem possible for small amounts of this débris locally to be preserved as arkose among the various glacial deposits. In New England, there is in several localities deep preglacial disintegration, showing that the mantle of disintegration of the Piedmont district probably extended in former times northward over this area. Arkose is apparently lacking however, in the New England glacial deposits. No example of this type of deposit is known to the writer.

2. *Marine and lacustrine.*—(*a*) The basal member of a new, transgressive marine series is commonly composed of the materials of the former regolith. If the shore forces are not too violent in their working over of the débris, the basal deposit in regions of granitic rocks may be arkosic. The constituent grains show more or less rounding. There may be present a small amount of argillaceous matrix. Through the elimination of the feldspar the arkose may grade into quartzite. Arkose deposits of this type may grade into deposits of the type discussed in (*b*).

To this type of deposit (*a*) there should be apparently referred:

Arkose of the Hotauto formation (pre-Cambrian), Shinumo Quad., Arizona.
The Cambrian arkose of Eastern United States (in large part)
The arkose (Silurian) of Littleton, New Hampshire (in part)
The arkose of the Igaliko formation (Devonian), Greenland
The arkose (Triassic) of the Morvan (in part), France
The arkose (Tertiary) of the Limagne (in part), France

(*b*) When erosion of the mantle of disintegration in a granitic terrane adjacent to the sea or to a lake occurs, deposition of the disintegrated material is likely to take place in the sea or lake with, as a consequence, the formation of arkose. Near the shore the arkose is in banks and lenses and is interstratified with beds composed of the material from the soil and zone of decomposition and of argillaceous material eliminated from the débris of disintegration. The constituent grains of the arkose are subangular to poorly rounded, the degree of rounding being greater in the more quartzose beds. There may in some cases be a slight amount of argillaceous matrix. Unless the feldspar is itself reddish, the arkose is grayish in color. Although not necessarily basal, the arkose is more likely to be near the base of the formation than not, since the change of conditions which causes the erosion of the mantle of disintegration is likely to mark the inauguration of a new period of sedimentation. The arkose formed far from shore is less granitic in appearance than that formed immediately at the shore, there is considerable rounding and sizing of the constituent grains, and there is elimination of much feldspar and argillaceous material. The arkose in many cases grades into quartzite.

An example of this type of deposit is the Tertiary arkose of the Limagne, France. During the Oligocene times the Limagne was

first a brackish-water basin some thirty km. in width and later a fresh-water lake lying then as now in the granite plateau of the Plateau Central. The arkose is found chiefly near the base and is found in banks alternating with greenish marl and in some cases extending out a considerable distance from the edge of the basin. Some of the arkose, especially that at Royat, is massive, coarse, composed largely of good sized fragments of the coarse phenocrysts of the underlying granite, and is extremely granitic in appearance. The greater part of the arkose, however, is much finer, is more quartzose, is composed of more-rounded grains, and grades into quartzite. There is in some cases an argillaceous matrix, in some cases a sericitic matrix, and, in some of the more quartzose phases, there is very little matrix. There is a general even horizontal stratification. Where cross-bedding is present in individual strata it is usually of the simple foreset type.

To this type of deposit are probably to be referred:

Much of the pre-Cambrian arkose of Ontario
Arkose of the Congo Series, French Hoeck, Cape Colony
The Cambrian arkose, North Carolina–Tennessee
Fitch Hill arkose, Silurian, Littleton, New Hampshire
Haybes arkose and Weismes arkose (Devonian) Ardennes–Eifel District
Arkose of the Grés bigarrés and Grés vosgien (Triassic) of the Morvan region, France
Dolomitic arkose (Keuper), Franconia and Thuringia
Arkose of the Blasensandstein and Coburgerbausandstein (Keuper), eastern Palatinate
Lower Stampian–Sannoisian arkose (Oligocene), Limagne, Forez, and Roannais basins, France
Much of the Jura–Cretaceous arkose of southwestern Alaska
Arkose of the Cutler formation (Permian), Colorado(?)
Arkose of the Fountain and Lower Wyoming formations (Permian), Colorado(?)

C. UNTRANSPORTED OR SEDENTARY ARKOSE

Basal, unstratified deposits grading into the underlying granite. When deposition begins in a district, the original regolith locally may be buried before it has been eroded to any considerable extent. It is thus possible for arkose to be formed without the usual intermediate steps of erosion, transportation and deposition of the

disintegrated material. The arkose is composed of the constituent minerals of the granite or gneiss in essentially their original proportions. Some of the silicates, especially the biotite, hornblende, and plagioclase, are in many cases highly decomposed. The constituent grains are angular. The upper part of the arkose may show a rude stratification and may grade upward into a well-stratified deposit. The lower portion is massive and grades downward into the granite, and may show the unaltered cores of bowlders of exfoliation.

A good example of this type of arkose is to be found in the lower arkose in the Silurian at Littleton, New Hampshire. Between the Niagaran Limestone and the granite there is from two to eighty feet of arkose which is coarse and granitic in appearance. The quartz and feldspar are the same as those of the underlying granite and are present in practically their original proportions. There is a slight amount of a fine-grained dark matrix. In its upper portion, the formation shows faint traces of stratification and in its lower portion it grades into the underlying granite-gneiss. Locally the original spheroidal weathering and the unaltered cores and shells of concentric weathering are distinguishable.

To this type of deposit are to be referred:

The arkose (in part) of the Vermont formation (Cambrian), Massachusetts and Vermont
The basal arkose (Silurian) at Littleton, New Hampshire
Pre-Cambrian arkose (in part) of the Cobalt District, Ontario
Basal arkose, Narragansett Basin, Massachusetts and Rhode Island
Nubian arkose, Aswan, Egypt

D. SUMMARY

The geological significance of arkose in brief, then, varies from case to case and cannot be limited in the general statement to significance of a special set of conditions. Each deposit is significant of some special set of conditions and these in many cases can be determined from the individual deposit or its associations. In the preceding discussions an attempt has been made to show a grouping of these in conformity with a genetic classification of arkose, each type of which is significant of some special type of

conditions. But even if the premises of this classification should be seriously disputed, it still remains a fact that most formations lying unconformably on a former granitic terrane have arkose at or near the base, and there seems to be a more or less general rule that, whenever a period of deposition is inaugurated over a granitic terrane, arkose is the first or one of the first deposits to be laid down, whatever the prevailing conditions. This basal arkose commonly shows but slight effects of wear and is apparently near the point of origin of its constituent material. At higher horizons, there often is yet other arkose, in most cases showing more signs of wear and apparently having been transported for a greater distance; and in still other cases, as has been noted, arkose composes the whole of a formation, thousands of feet in thickness. The deposits are of such differing types and have such different associations with coal measures, with mud-cracked red beds, with beds containing faceted pebbles, and with beds carrying marine fossils, that the old conception of the limited significance of arkose is manifestly incorrect, and arkose must be significant of several types of conditions.

AN UNUSUAL FORM OF VOLCANIC EJECTA[1]

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In the course of a study of the eruption of Taal Volcano, in southwestern Luzon, Philippine Islands, during the month of February, 1911, I noted the presence of small concretion-like bodies in the finest-grained portion of the blanket of fragmental ejecta which the eruption spread over the surrounding country. It will be recalled that the eruption in question was characterized, by the expulsion of great volumes of water-vapor, charged with ash or sand, together with a small proportion of coarser fragmental material. The eruption destroyed completely a dozen small villages, with attendant damage to crops and live stock, and killed 1,335 people. A thin layer of mud and dust was spread over an area of about 1,000 square kilometers, extending principally to the north and west of the crater. I commented upon the presence of the spherical bodies in the ash-fall at the time as follows:

> An interesting feature of the fall of the ejecta is the formation of drops or balls of mud. These were observed most abundantly on the island itself, but were seen at Talisay and Bañadero also. They range in size from large shot to hazelnuts, and when broken sometimes show concentric markings. Apparently they fell late during the activity, being found just below the surface of the deposit. These mud balls cannot be classed as lapilli in the strict sense of that term, since they are built up, probably through the condensation of steam into drops of water. The accompanying vertical section of the fall of mud or ash [text Fig. 2] was taken on the southwest slope of the volcano.[2]

Text Fig. 2, referred to in the quotation, is reproduced herewith as text Fig. 1.

Taal Volcano forms an island near the center of a lake from 15 to 20 kilometers in diameter. Thus the mud balls, which were found both on the slopes of the volcano and at the villages of Talisay

[1] Published by permission of the Director, Bureau of Science, Manila, Philippine Islands.

[2] Wallace E. Pratt, *Phil. Jour. Sci.*, Sec. A (1911), VI, 71.

and Bañadero on the margin of the lake, from 6 to 8 kilometers distant from the crater, must have been widely distributed; nevertheless, at the time I was inclined to attribute their formation to accidental, rather than to common, conditions of explosive volcanism. The literature accessible to me revealed little evidence that ejecta of this character had been observed generally, although the following description by Edward Otis Hovey of "drops of mud," which he encountered after the eruptions on Martinique in 1902, shows that similar phenomena have been noted:

> In addition to the showers of dry dust and ashes, there fell during the eruption an immense amount of liquid mud which had been formed within the eruption cloud through the condensation of its moisture. This mud formed a tenacious coating over everything with which it came in contact. That drops of mud, too, formed in the air and fell as a feature of the eruption is proved by the condition of the walls the of houses in Precheur, on which I found flattened spheroids of dried mud which could have formed only in the manner indicated. These flecks of mud were two, four, and even six inches across, where two or more had coalesced. They occurred mostly on the northern and eastern walls of the houses. The testimony of the people as to the occurrence of rain during the great eruption is conflicting, but the evidence of the coating and these drops of mud proves that much aerial condensation of steam accompanied these outbursts.[1]

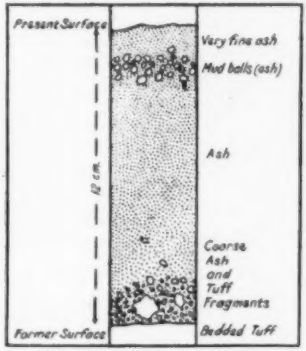

FIG. 1.—Section of ash which fell on the southwestern slope of Taal Volcano in January, 1911, showing balls of dried mud near top of layer.

More recently I have come upon evidence which leads me to the belief that the formation of mud balls has been rather characteristic of that type of volcanic activity which results in the explosive eruption of great clouds of dust-laden steam, at least where atmospheric conditions similar to those on the island of Luzon prevail. In the examination of samples of strata pierced in drilling for artesian water at the towns of Bauan and Taal, distant 25 and 15 kilometers, respectively, from the crater of Taal Volcano, abundant

[1] Edward Otis Hovey, *Am. Jour. Sci.*, XIV (1902), 343.

spheroidal and ellipsoidal inclusions were found which are indistinguishable from the mud balls of the last eruption of Taal. These ejecta may have come from Taal itself, or from some other of the numerous small craters which are known to have existed in southwestern Luzon formerly. The wells were drilled by the Bureau of Public Works with standard drilling rigs, and the samples

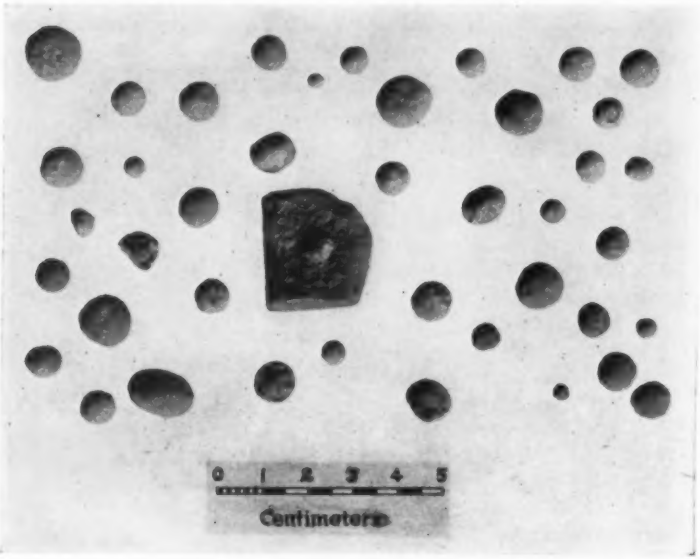

FIG. 2.—Photograph of balls of dried mud which fell with the fine tuff portion of the ejecta of Taal Volcano, in the eruption of 1911.

studied were submitted by the drillers. The balls of dried mud came from depths of from 100 to 150 meters in very loosely consolidated, silt-like volcanic tuff, fragments of which had evidently caved into the well and had been brought to the surface by the sand pump or bailer. Some of the balls were broken, but many were intact in spite of the disintegrating effect which the rushing action of the water into the bailer must have caused.

The size and appearance of the balls are well shown in the accompanying photograph (Fig. 2). One specimen still imbedded

in the tuff appears near the center of the photograph. The broken surfaces display clearly the concentric structure which is characteristic of these bodies. The balls can be disintegrated between the fingers when wetted, and the individual particles prove to be like dust in size. That these aggregates have not resulted from solution processes nor from dynamism is evidenced by the facts that they do not contain calcium carbonate nor any other extraneous cementing agent, and that the beds in which they occur have certainly not experienced metamorphism. The theory which Dr. Hovey advanced to explain the presence of "drops of mud" in the ejecta from Mont Pelée accounts satisfactorily for the similar, although apparently smaller, balls of dried mud in the loose tuffs of southwestern Luzon.

W. H. Brown, botanist, Bureau of Science, has submitted to me several hundred balls of dried mud which he found included "in the upper part of a thick bed of volcanic tuff" on the slopes of Mount Maquiling, an extinct volcano about 20 kilometers northwest of Taal. He had been engaged in a study of the flora of Mount Maquiling and had encountered these balls in the course of a soil survey. They are precisely like those already described in shape and structure, but many of them are larger and they have a brownish-yellow color, whereas the Taal products are light gray in color. They consist of the same material as the inclosing bed—clayey, fine-grained tuff. The balls from Maquiling attain a diameter in rare specimens of as much as 4 centimeters, thus being comparable in size with the drops of mud observed by Dr. Hovey, and are so hard that they can be broken only with difficulty between the fingers. The appearance of a face in the tuff bed containing these balls is shown in Fig. 3. The concentric structure of the balls is again revealed in this photograph.

Recently, also, I have encountered well-preserved balls inclosed in clayey tuff on Bondoc Peninsula, Tayabas Province, and near the Santa Lutgarda iron mine at Angat, Bulacan Province, widely separated parts of Luzon. The tuff beds in these localities are of greater age than the recent tuffs in the Taal volcanic region, dating back, probably, to the late Miocene. The tuff is slightly indurated, but the balls have retained their form and display

clearly the characteristics already recorded in describing the ejecta from Taal. I am confident that they originated in the same manner in each case.

The suggestion arises, in view of the foregoing observations, that the condensation of mud into drops or balls must be a rather common feature of volcanic eruptions which throw out great clouds of water-vapor and fine sand or dust. The product may be

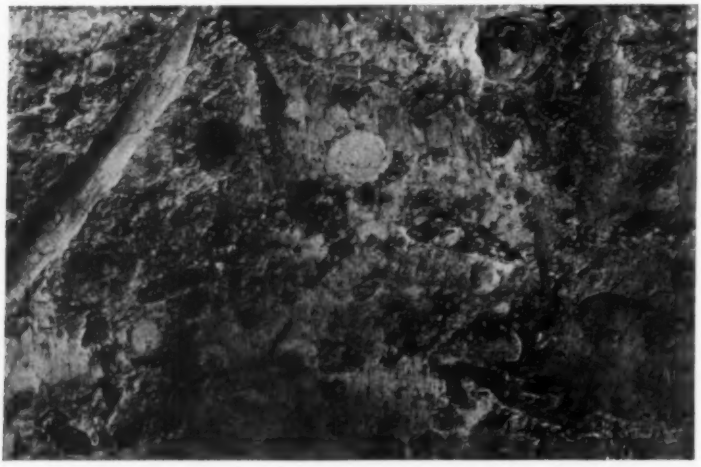

FIG. 3.—Photograph showing close view of a face in a bed of clayey tuff containing "mud balls"; slopes of Mount Maquiling, southwestern Luzon. About one-third natural size.

described, perhaps, as a volcanic hailstone. Undoubtedly, the contour of such bodies is often destroyed by the impact of the fall to the ground surface. Probably only where the drops have had opportunity to dry out somewhat before reaching the earth and where they strike in soft, unconsolidated beds of recently fallen tuff, is their form preserved under subaerial conditions. It would appear to be equally remarkable that they should retain their form upon falling into water. Yet it is beyond question that the tuff series into which the wells at Bauan and Taal penetrated is in great part water-laid, and it is to be presumed that the mud

balls encountered in the wells at these towns fell into the sea originally.

Unless conditions peculiar to the tropics, such as high temperature and, perhaps, excessive humidity, are essential factors in the phenomena which have been described, it would appear that mud balls should have been formed in the eruption cloud from Katmai Volcano in Alaska and in the recent eruptions of Mount Lassen in California. So far as I have observed, none of the published accounts of the eruptions of these volcanoes have mentioned ejecta of this character.

RIPPLE-MARKS IN OHIO LIMESTONES[1]

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INTRODUCTION

ORDOVICIAN RIPPLE-MARKS
- Elk Run
- Cherry Fork
- Trebers Run
- Review of Previous Work

SILURIAN RIPPLE-MARKS
- Beasleys Fork
- Lick Fork
- Sproull Glen
- Lawshe Quarry
- Elk Run
- Sharpsville
- Near Peebles
- Near Locust Grove
- Leesburg
- Monroe Formation

DEVONIAN RIPPLE-MARKS
- Sandusky

INTRODUCTION

Dr. Edward M. Kindle, in a "Note on a Ripple-Marked Limestone" in the Devonian of northern Manitoba, published in 1912, stated that: "the occurrence of ripple-marks on sandstone is a common phenomenon to every geologist. . . . . The literature on ripple-marks relates almost entirely to these familiar sand or sandstone ripples. The occurrence of ripple-marks on limestone seems to be a phenomenon of such relative infrequency that it appears desirable to record an example which has come under the writer's notice."[2] In a later paper Dr. Kindle has described ripple-

[1] Published by permission of the State Geologist of Ohio.

[2] *Ottawa Naturalist*, XXVI (December, 1912), 1 (reprint).

marks in the Trenton limestone near Hull, Quebec,[1] and given a summary of previously described ripple-marks in American limestones.[2] At an earlier date Dr. August Foerste had noted the occurrence of wave-marks (ripple-marks) in the Ordovician and Silurian limestones at a number of localities in Kentucky, Ohio, and Indiana.[3] Recently Professor J. A. Udden has described ripple-marks in the Burlington limestone of Iowa and in limestones of Comanchean age in Texas.[4]

On account of the comparative infrequency of described observations of ripple-marks in limestone the writer has concluded to record the most conspicuous of those which he has seen while engaged in field work in Ohio. These will be grouped in the several geologic systems in which they were observed, arranged in ascending order.

ORDOVICIAN RIPPLE-MARKS

Elk Run.—The best ripple-marks seen in the Ordovician are in the upper part of the Richmond formation on Elk Run in the northwestern part of Adams County. This locality is on the Marion Dunlap farm, about $1\frac{1}{4}$ miles east of Winchester and 3 miles west of Seaman, where the ripple-marked layer of limestone forms the floor of the run for a considerable part of the distance between the Norfolk & Western Railway trestle and the highway bridge. An excellent view of these ripple-marks may be had from the Norfolk & Western passenger trains while crossing the trestle if one looks downstream to the north.

The first series of ripple-marks is on a layer forming the bed of the run a short distance below the trestle and continuing up a branch from the west for about two rods. The direction of the ripple-marks is about due north and south. The more gradual slope (stoss) is to the east, and the steeper (lee) to the west. The distance apart (amplitude) of the crests varies from 28 to 32 inches

[1] *Jour. Geol.*, XXII (1914), 707–9.

[2] *Ibid.*, pp. 709–11.

[3] *Jour. Geol.*, III (1895), 50–60 and 169–97; 1–40 (reprint); *Jour. Cincinnati Soc. Nat. Hist.*, XVIII (1896), 167; *Am. Geologist*, XXXI (1903), 333–61.

[4] *Jour. Geol.*, XXIV (March, 1916), 125, 126; illustrated by Fig. 3, p, 126, Fig. 4, p. 127, and Fig. 5, p. 128.

in the more normal ones, with, in some instances, shorter and more irregular ones between these crests. The depth of the troughs, from the crest to the bottom, varies from 2 to 3 inches. The crests undulate or curve slightly in crossing the surface of the limestone, and this undulation is conspicuous in the bed of Elk Run a little below the branch. Fig. 1 shows the ripple-marks in the

FIG. 1.—View of ripple-marks in bed of Elk Run, just below the Norfolk & Western Railway trestle, 1¼ miles east of Winchester, Ohio. Photograph by C. S. Prosser.

bed of Elk Run, just below the railway trestle, and also on the same layer of limestone in the bed of the small western branch.

There is a dip of at least 1° to the east as measured on the crests of the ripple-marks in the lower part of the branch, and farther up this stream it increases to 2°. The layer of limestone contains large numbers of shells which Dr. Foerste states are covered by sand.[1] It is rather difficult to make out the sand, although there is granular material to some extent. This horizon

[1] *Jour. Geol.*, III (1895), 59.

is given by Dr. Foerste as 60 feet below the top of the Richmond formation.[1]

The dip downstream carries this ripple-marked layer down Elk Run to where it covers the entire bed of the stream for some distance above the highway bridge. At this locality the bed of the stream which is covered by the ripple-marked layer is some 60 feet wide and extends 156 feet along the bed of the stream. This is a beautiful example on a large scale of a ripple-marked limestone. The trend of the crests of some of these ripple-marks is N. 3° W., and they undulate to a considerable extent in crossing the stream. The crests of the normal ripple-marks are from 27 to 32 inches apart. The crests of about three out of five are 29 inches apart, and the average over different parts of the surface of this layer is 29, 30, and 31 inches apart. The more gradual and longer slope (stoss) is to the east, the steeper and shorter slope to the west, and the ripple-marks are clearly asymmetrical. A view of the ripple-marked bed of Elk Run at this locality, looking downstream toward the highway bridge, is shown in Fig. 2. A view of the bed of Elk Run from the highway bridge looking upstream, with the railway trestle in the distance, is shown in Fig. 3.

The layers on the western side of Elk Run below the highway bridge are dipping from 3° to 4°.5 N. 10° E. The majority of readings on the different layers, however, gave 3° for the amount of dip. The barometer gave a dip of 5 feet to the east for the surface of the ripple-marked layer from the branch to the bed of Elk Run under the highway bridge, a horizontal distance of 500 feet.

Just below the highway bridge on the western bank is a ripple-marked layer, between 2 and 3 feet higher than the fine one in the bed of Elk Run which has just been described. The ripple-marks of this higher layer run N. 30° W., are not so conspicuous as in the lower layer, and do not show much difference in the slope of the two sides. On the western side of Elk Run, not far below the highway bridge, is the house of Mr. Charles L. Bailey, and near water-level above the house is a set that runs about northwest and southeast. The eastern slope of these ripple-marks is more gradual than the western slope. Just below the Bailey house a

[1] *Ibid.*, p. 58.

fall is formed by a ripple-marked layer in which the ripples run N. 3–5° W., and the steeper slope is to the west. The crests are from 27 to 28 inches apart, and the ripples are more irregular than those in the bed of Elk Run above the highway bridge. It is not certain that this is the same layer as the one above the highway bridge, and Mr. Bailey, who is interested in geology, states that

FIG. 2.—View of ripple-marked bed of Elk Run, looking downstream toward the highway bridge. Photograph by C. S. Prosser.

it is lower. Below the ripple-marked layer in the fall is another one with the ripples running N. 10° W., and the steeper slope to the east, with a more gradual one to the west.

Farther down Elk Run, shown for some rods in the bed of the stream and making a lower fall, is a conspicuous ripple-marked layer, which is 5+ feet below the one forming the Bailey fall. These ripple-marks run N. 10–16° W., the crests are undulating, the slopes steeper to the west than to the east, and the crests from 21, 26, to 27 inches apart. Farther down the run on the eastern side, opposite the E. E. Jamison house, where the pike comes down into

the valley of the stream, is a ripple-marked layer. The ripple-marks are not so clearly defined as in the layers farther up the stream; but they apparently run about north and south. Loose blocks of limestone containing pebbles were noted at this locality; but the layer was not located in place. Probably this is the locality described by Dr. Foerste when he says, "Within half a

FIG. 3.—View of ripple-marked bed of Elk Run from the highway bridge looking upstream, with the railway trestle in the distance. Photograph by C. S. Prosser.

mile of the bridge, farther down, opposite a house on the east bank, plenty of pebbles occur in the rock."[1] Farther down the stream, below the next house on its western side and a ford, is a still lower layer, with not very clear ripple-marks.

As noted above, the ripple-marks in the limestones along this stream were first described by Dr. Foerste as wave-marks on Elk Horn Creek.[2]

Cherry Fork.—Ripple-marks in the Upper Richmond were also seen in the bed of Cherry Fork, below the highway bridge at

[1] *Op. cit.*, p. 59. [2] *Ibid.*, pp. 58–60.

Harshaville, 4 miles southeast of Seaman, Adams County. The ripple-marks in the highest limestone layer below the bridge run about N. 60° W. and have the more gradual slope to the east of south, and the more abrupt to the west of north. The crests vary from 20 to 28 inches apart. In another limestone layer about 6 inches lower than the first one the ripple-marks run north and south, with the steeper slope to the west and the more gradual one to the east. The crests are from 20 to 30 inches apart. Over part of the floor of the creek below the bridge is a less distinctly ripple-marked layer between the two which have just been described. These run almost directly northwest and southeast, the crests are from 22 to 28 inches apart and are rather flat, and the slope is about the same on each side, making them nearly symmetrical. The northeast slope on a few of them is a little steeper and these do not have such flat crests. Perhaps the tops of the crests of the others have been worn away, which gives them the present somewhat flattened form.

Trebers Run.—This stream is a western tributary of Lick Fork (called Lick Creek on the Highway Map of Adams County), about 5 miles northeast of West Union, 2½ miles below Young's Chapel, about a mile above Dunkinville, and 9 miles southwest of Peebles. On the southern bank of Trebers Run, about 150 yards above the covered bridge on the West Union and Jacksonville Pike, is a ripple-marked limestone layer exposed for 90 feet or more along the bank. This limestone layer is in the upper part of the Richmond formation. At the time this locality was visited the streams were high and the layer was partly covered by water, so that the conditions were not especially favorable for study. Three adjacent ripple-marks run as follows: N. 12° E., N. about 12° E., and the third one about N. and S. The distance between the crests varies from 2 feet 2 inches to 2 feet 7 inches, while the depths of the furrows (troughs) is from 2½ to 3 inches. The eastern slope of the ripple-marks is perhaps a little steeper; but there is comparatively little difference in the slope of the two sides. There is a heavy dip for this region downstream to the east, and certain layers on the northern bank some rods farther up the run dip from 4°.5 to 5° N. 100° E.

This stratum is known locally as the "washboard" layer, and it is apparently the one described by Dr. Locke in 1838. He stated that "the waved stratum at Treber's is exposed in the bed of the fork, about 400 feet in length, and 50 feet in width."[1] Mr. William Treber, now eighty-nine years old (July, 1915), who lives on the Treber farm just south of the run, remembers when Dr. Locke studied this locality, and his daughter, Lizzie Treber, stated that the layer described by Locke is believed to have been exposed in the field a few rods northeast of the lower part of Trebers Run, on the eastern side of the Pike. Lick Fork has shifted its bed somewhat to the east and the locality is now covered by soil. The strong easterly dip would probably carry the layer now exposed on Trebers Run down to the locality where it is stated that the ripple-marks described by Dr. Locke were exposed. The barometer gave a difference in altitude of 110 feet from Lick Fork at Trebers to the top of the Richmond formation on Lick Fork above Young's Chapel, $2\frac{1}{2}$ miles above Trebers. Miss Treber also stated that formerly the ripple-marked layer was exposed in Lick Fork, about opposite their house, as well as above it; but the high water at the time this locality was studied prevented determining whether any of the layer is now shown when the water in the stream is at its normal height.

Review of previous work.—Ripple-marks in the Upper Richmond in Ohio, so far as known to the writer, were first described by Professor John Locke from outcrops on Lick Fork,[2] about 5 miles northeast of West Union, Adams County. Locke called it the "waved stratum" and located its horizon as 55 feet below the top of the blue limestone, No. V of his section, and he stated that near a house known as Trebers it was exposed "in the bed of the fork, about 400 feet in length, and 50 feet in width."[3] Professor Locke, however, stated that "these waves are not local, but may be traced in the same stratum over tracts of many miles. They have been called 'ripple marks'; but all geologists will agree that the blue limestone has been formed far below the reach of 'ripples.'"[4]

[1] *Second Ann. Rept. Geol. Survey Ohio*, 1838, p. 247 and bottom of Pl. 6, opposite p. 242.

[2] *Second Ann. Rept. Geol. Survey Ohio*, 1838, pp. 246, 247, and Pl. 6, opposite p. 242.

[3] *Ibid.*, p. 247. [4] *Ibid.*, p. 246.

Messrs. Joseph Moore and Allen D. Hole have described "ripple-marks in Hudson River limestone, in Wayne County, Indiana, 5 miles southwest of Richmond," which are illustrated by 3 plates.[1] These are probably in the Richmond formation and it is stated that "the mean distance from crest to crest is approximately uniform for the series, and the average for twenty such distances is found to be 2.63 feet. The average depth of lowest part of troughs below crests is $1\frac{1}{2}$ to $1\frac{6}{10}$ inches."[2] At an earlier date W. P. Shannon had described "wave-marks on Cincinnati limestone" in the bed of Salt Creek, 3 miles west of Oldenburg, in the southwestern part of Franklin County, Indiana.[3]

Dr. Orton called attention to the observations of Professor Locke and stated that "it is an even more striking characteristic of the rock in its lower beds [Cincinnati group], as shown in the river quarries of Cincinnati, or in the lowermost 100 feet that are there exposed. . . . . The interval between the ridges varies, but in many instances it is about 4 feet. The greatest thickness of the ridge is 6 or 7 inches, while the stone is reduced to 1 or 2 inches at the bottom of the furrow, and sometimes it entirely disappears."[4] Dr. Foerste also noted wave-marks and ripple-marks in the "Lower Hudson, or Utica" opposite Cincinnati, at West Covington, Kentucky,[5] which in general "run slightly east of north."[6] Recently Dr. Kindle has reported Dr. Foerste as stating that "wave-marks (ripple-marks) occur in Ohio, Indiana, and Kentucky, in abundance in the Lower Eden, Upper Richmond, and Upper Brassfield limestones. They occur in great numbers, but not so abundant, also in the Middle Eden. In Kentucky they are common also locally in the Mount Hope bed, at the base of the Maysville. They occur often near the middle of the Arnheim and at various intervals in the Lower and Middle Richmond in the three states mentioned."[7]

[1] *Proc. Indiana Acad. Sci.*, 1901 (1902), pp. 216–20.

[2] *Ibid.*, p. 217.

[3] *Ibid.*, 1894 (1895), pp. 53, 54.

[4] *Rept. Geol. Survey Ohio*, I (1873), 377.

[5] *Jour. Geol.*, III (1895), 56–58.

[6] *Ibid.*, p. 58.

[7] *Ibid.*, XXII (1914), 709, 710.

SILURIAN RIPPLE-MARKS

Beasleys Fork.—Ripple-marks in the upper part of the Brassfield limestone (formerly called Clinton) were noted at several localities in Adams County. One of these localities is in the bed of the upper part of Beasleys Fork, some distance above the house of Walter D. Grooms, which is about 1½ miles south of West Union on the Wrightsville Pike. This stream is crossed by three layers of limestone in which ripple-marks are conspicuously shown.

The lowest layer is a very crinoidal limestone, from 3 to 10 inches thick, which forms a small fall, and its top is about 8 feet 3 inches below the top of the Brassfield limestone. The ripple-marks run about east and west, with the more gradual slope to the north and the steeper toward the south. The top of the second or middle ripple-marked layer is 4 feet 11 inches below the top of the Brassfield formation, and the layer itself is 5± inches thick, but the ripple-marks are not so conspicuous as in the layer below and the one above. These ripple-marks run north and south with the steeper slope on the east side and the more gentle slope on the west. Finally, there is the third or highest ripple-marked layer, the top of which is 4 feet 5 inches below the top of the Brassfield, and opposite the small house on the bank of the creek on the Joe Morrison farm. The layer is a grayish, somewhat greenish-spotted, crystalline limestone, 8± inches thick. The ripple-marks run about north and south, with the steeper slope to the east and the more gradual to the west. These ripple-marks are heavy and the crests are 26, 31, 34, 35, and 38 inches apart. The distance from the bottom of the trough to the top of the ridge varies from 3 to 9 inches.

These ripple-marks were noted by Dr. Foerste in his description of the section "along the road to Beasley Fork." The following is that part of this section in which the ripple-marks occur, as described by Dr. Foerste:[1]

	Ft.	In.
Limestone, wave-marked		3
Clay		8
Limestone		3
Clay		3

[1] *Kentucky Geol. Survey, Bull. No. 7*, 1907, p. 42.

	Ft.	In.
Limestone, with large wave-marks		6
Limestone		6
Clay, with a little thin limestone	1	6
Limestone with large wave-marks and containing large crinoid beads		6

Lick Fork.—At least two ripple-marked layers in the upper part of the Brassfield limestone occur on Lick Fork (called Lick Creek on the Highway Map of Adams County) above and below the highway bridge on the West Union and Jacksonville Pike, about $2\frac{1}{4}$ miles northeast of West Union and about opposite the house of J. Frank Young. Stratigraphically, what is apparently the lowest ripple-marked layer outcrops a few rods above the bridge, where there is a strong dip downstream. The rock of this layer is a very crystalline and crinoidal limestone containing large cup corals and numerous fragments of other fossils in its upper surface. The ripple-marks are large and one of them runs N. 70° E., although some of them run perhaps more nearly east and west. The crests of two of them are 30 inches apart, and of another set 31 inches apart. The trough is $3\frac{1}{2}$ inches deep and the slope much steeper on the southern than on the northern side. A few rods below the bridge is a layer with ripple-marks which run N. 20° W. and S. 20° E. The crests of these ripple-marks are about 31 inches apart and the western slope is steeper than the eastern one. This ripple-marked layer is about $19\frac{2}{3}$ feet higher than the base of the Brassfield limestone. Not far above the highway bridge are ripple-marks running N. 18° W. and S. 18° E., which apparently occur in the same layer as those below the bridge, which have just been described. Farther upstream the direction of the ripple-marks, apparently on this same layer, has changed to N. 74° W. Not much farther upstream than the ripple-marked layer first described one is shown in the bed of the stream, which may be higher than the others; but its stratigraphic position was not certainly determined. The ripple-marks of this layer run north and south, the crests are 30–35 inches apart, and there does not appear to be a marked difference in the angles of the slopes.

This is probably the locality where Professor John Locke noted two waved layers in the Flinty limestone (Brassfield), No. III of his

section, on Lick Fork.[1] He gave the top of the upper one (No. 13) as 4 feet 9½ inches below the top of a flinty layer (No. 1) (apparently one of the layers of the Dayton limestone), which he seemed to consider the top of the flinty limestone.[2] This upper "waved stratum" is given as 3 inches thick, with 20 inches mostly of marl between it and the lower "waved layer" (No. 17) which is reported as 7 inches thick.

Sproull Glen.—This glen is on the R. C. Sproull farm, now owned by Mrs. Jennie Black and Dr. O. T. Sproull, not far from Sproull Bridge over Ohio Brush Creek, 6 miles southwest of Peebles. The heavy rains of July, 1915, had deepened and cleared out the bed of this stream to such an extent that three layers of ripple-marked limestone were exposed which on a visit to the same glen in September, 1914, were not seen.

The lowest ripple-marked layer was shown on the northern side of the stream with ripple-marks running N. 10° W. to N. 30° W. One foot 5 inches higher is another limestone layer 7 inches thick with ripple-marks imperfectly shown on its upper surface. Also 3 feet higher ripple-marks occur on thin layered limestones; but the last two layers were so poorly shown that not many data could be obtained concerning the ripple-marks. The top of the third or highest ripple-marked layer is 9 feet 9 inches below the base of the 10-inch zone of *Whitfieldella quadrangularis* Foerste[3] in the Brassfield limestone, and 9 feet 3 inches below the top of this formation as exposed in the third fall, or 13 feet 6 inches below the top of the very hard Dayton limestone as exposed in the stream above this fall.

Lawshe quarry.—This old quarry is located on the Vincent Robbins farm, north of Lawshe, Adams County, on the Cincinnati Division of the Norfolk & Western Railway. Ripple-marks were noted near the western end of the quarry, which are not well exposed but run N. 16° E. The ripple-marked layer occurs from 1 foot 4 inches to 2 feet below the base of a rather conspicuous 2 foot 2 inch

[1] *Second Ann. Rept. Geol. Survey Ohio*, 1838, pp. 244, 246, and Pl. 6, opposite p. 242, on which only one waved layer is indicated in the flinty limestone.

[2] *Ibid.*, p. 244, where he states that "the upper layer of the flinty stratum is peculiarly marked. It is about one foot thick, and contains so much silex that it has the sharp conchoidal or flinty fracture, and gives fire with steel."

[3] *Kentucky Geol. Survey, Bull. No. 7*, 1906, p. 41.

layer, which is 12 feet 10 inches above the top of the "chert zone" in the basal part of the Brassfield limestone and 16 feet 10 inches higher than the lowest outcrop in this quarry. The 2 foot 2 inch layer is variously colored crystalline limestone, which on the weathered faces is apparently cross-bedded and contains a good many pebbles, more or less flat, and some of them of considerable size. The top of the massive layer just described is about 22 feet below the top of the Brassfield limestone and nearly 24½ feet below the top of the hard Dayton limestone.

Elk Run.—On Elk Run (called Elm Run on the Highway Map of Highland County), 2¼ miles northeast of Belfast, Highland County, are ripple-marked layers in the Brassfield limestone, which are well shown in the stream a few rods below the iron highway bridge on the upper road from Belfast to Elmville. This layer is a crystalline limestone, from ½ to 3 inches thick, which contains fossils and some pebbles. The ripple-marks run N. 80° E., the steeper slope is to the north and the more gradual one to the south. The crests range from 26 to 36 inches apart, 32 inches being the most frequent distance. The deepest trough noted is about 2½ inches lower than the crest. A ferruginous limestone 1 foot 4 inches thick occurs just above the crystalline, ripple-marked layer, and another 4-inch ferruginous limestone layer just above this, the upper surface of which is apparently ripple-marked. Below the ripple-marked, crystalline limestone is a layer 1 foot thick containing fossils and numerous pebbles of Brassfield limestone. The majority of the pebbles are rather flat and fairly well rounded on the margins. The size of some of the larger pebbles is indicated by the following figures: one 8½ inches long, and three rectangular ones respectively 9×6, 9×8, and 9×8½ inches. The pebbles as a rule lie flat (horizontal) or at least nearly so in the rock; but there are some that are imbedded at more or less of an angle.

Attention was first called to this locality by Dr. Foerste, who has written as follows concerning it:

> By far the most interesting feature of the locality, however, was the presence of great wave-marks, wonderfully distinct and well exposed for a distance of a hundred feet down the creek. The line of strike of these wave-marks was magnetically about north 65° east. The crests of the wave-marks

were about two inches above their greatest depressions, and the distance from one crest to the next was on the average about 28 inches. They sloped northwards a little more steeply than southwards. This wave-marked layer is only from one to two inches in thickness, and immediately overlies a great mass of pebbles, imbedded in the Clinton just beneath. These pebbles sometimes project strongly into the sandy layer above, which shows the wave-marks. The pebbles are on the average larger than at any place where pebbles have so far been seen in the Clinton. Plenty of them are 12 inches in

FIG. 4.—View of ripple-marks as formerly shown in the old Schoepfle quarry, Sandusky, looking southeast. Photograph by C. W. Platt.

diameter, and many of them range between four and eight inches. As usual, the pebbles are only an inch to an inch and a half in thickness. Lithologically they are similar to the sandy stratified layers of the Clinton limestone, found characteristically in the lower half of the Clinton in this part of the state, and occurring also at higher levels. If there had been any doubt hitherto about the Clinton age of these pebbles, it was dispelled by the fossils found in some of the pebbles at this locality.[1]

Sharpsville.—On Turtle Creek, above Sharpsville, in the western part of Highland County, ripple-marks were noted in the Brassfield limestone; but there was not an opportunity to measure

[1] *Jour. Geol.* III (1895), 184.

them. Opposite Sharpsville and farther down Turtle Creek than the place above mentioned Dr. Foerste reported "a thin, sandy layer, very undulated, like ripple-marks where waves have crossed from various directions. Their importance was not appreciated, when observed, and their direction was not carefully noted. Judging from the memory alone the larger ripples had a general northeast course and indicated currents transverse to this direction."[1]

Near Peebles.—In the Peebles Stone Company quarry, on the northern side of the Norfolk & Western Railway, one-half mile west of Peebles, is a layer 7 feet 10 inches above the base of the West Union limestone, the surface of which is conspicuously ripple-marked. The rock is bluish gray in color, massive, contains Brachiopods, and the upper surface is very crinoidal. On the crests of the ripple-marks are furrows which are apparently trails. The majority of the ripple-marks run in a regular direction, which is N. 6° W.; but an occasional one runs in an irregular direction. The distance between two parallel crests is 27 inches and the trough is 1½ inches deep. The distance between two other conspicuous crests is 3 feet 10 inches, with a much smaller ripple-mark about half-way between them. In general the eastern slopes appear to be the steeper, although part of them do not show any particular difference, and one is apparently steeper on the western side.

About one-fourth mile west of Peebles in the bank of a small stream on the northern side of the Norfolk & Western Railway ripple-marks occur in Niagaran limestone. Ripple-marks are clearly shown in two layers of crinoidal limestone at this locality. In the lower layer one of the ripple-marks runs N. 6° W., and another one, N. 2° W. The crests are 22–23 inches apart and one trough is 4 inches deep. In general the more gradual slope is to the east and the steeper to the west, although in one of them the eastern slope appeared to be the steeper. In the upper layer the ripple-marks run N. 5° E., the crests are 44–45 inches apart, a trough is 4½ inches deep, and the steeper slope is to the east.

This locality was described as follows by Dr. Foerste:

> Along the railroad about a quarter of a mile west of Peebles, where the railroad crosses a creek, there are very good wave-marks in the rock on the

[1] *Jour. Geol.*, III (1895), 178.

north side of the railroad, in a sort of quarry. The rock is of a bluish tint, and is some distance above the Niagara shales. It is presumably of the Springfield horizon. The crests of the waves run here north 3° east; they are about 3½ inches above the troughs of the waves, and are about 42 inches apart, showing therefore approximately the same characteristics as the waves of Clinton age in Elk Run. They descend more rapidly eastward than westward. The wave-marks are seen at several levels through a thickness of 2½ feet

FIG. 5.—Nearer view of part of layer shown in Fig. 4. Photograph by C. W. Platt.

of rock. . . . . Where the railroad crosses the creek, 50 feet towards the southeast, the wave-marks are shown over a larger area. The crests here run north 5° west.[1]

Dr. Kindle has also made reference to this locality.[2]

Another locality of Niagaran ripple-marks is southwest of Peebles on the dirt road for Lawshe, about one-fourth mile west of the West Union and Locust Grove Pike. The ripple-marks are shown in the highway to the west of a run, and the first house to the west is that on the farm of James Graham. The ripple-marks run north and south, the crests are 20, 21, and three of them 24 inches apart. The more gentle slope appears to be to the west

[1] *Jour. Geol.*, III (1895), 190. [2] *Ibid.*, XXII (1914), 711.

and the steeper to the east. These ripple-marks occur in somewhat thin-bedded dolomites, like those to the west of Peebles, called Springfield by Dr. Foerste, and apparently are in the southern continuation of those beds.

Near Locust Grove.—On the western side of Locust Grove branch of Crooked Creek, 1 mile west of Locust Grove and nearly opposite the house of James Ogden, in the West Union limestone are ripple-marks running N. 12° W. and S. 12° E. Some rods farther downstream and 30 feet higher on the bank in the West Union limestone are rather large ripple-marks running N. 10° W. and S. 10° E.

Leesburg.—Ripple-marks occur in Lee's Creek in the gorge below the Davis Mill and north of Leesburg in the northern part of Highland County. The ripple-marks occur in the Blue Cliff dolomite, which Dr. Orton correlated with the Springfield dolomite, and just below a massive layer 7½ feet thick, which is well shown on the eastern side of the creek where the rock has been quarried to a small extent. The ripple-marks are rather irregular; but one runs N. 30° E. and they appear to be steeper on the western slope than the eastern.

Monroe formation.—Ripple-marks were noted at three horizons in the Monroe formation, 2½ miles east of Peebles; but the area exposed in each case was too small and the ripple-marks too imperfect to make any definite measurements. The lowest layer is exposed in the bed of Morrison Run some distance below the spring and house of John K. Morrison, on the road to Bacon Flat schoolhouse, and it is about 15 feet higher than the base of the formation. The highest one is shown in the highway leading up the hill to the west of the John K. Morrison house, and is stratigraphically some 86 feet higher than the base of the Monroe. The direction of these ripple-marks is somewhat irregular; but they run about east and west. The third and intermediate horizon is on a layer in the Virginia Product quarry, just south of the Norfolk & Western Railway, about 2½ miles east of Peebles, and it is more than 25 feet above the base of the Monroe dolomite.

DEVONIAN RIPPLE-MARKS

Sandusky.—The best example of ripple-marks in the Devonian limestone that the writer has seen is in Plant No. 2 of the Wagner

Stone Company (formerly known as the Schoepfle quarry), on Hancock Street in the southern part of Sandusky. Formerly there was a considerable area of the floor of this quarry on which ripple-marks were beautifully shown, the three views of which reproduced in this article were furnished by Mr. DeLos C. Ransom, of

FIG. 6.—View of ripple-marks as formerly shown in the old Schoepfle quarry, Sandusky, looking northeast and at right angles to Fig. 4. Photograph by C. W. Platt.

Sandusky, Ohio, who first called the writer's attention to them in January, 1902. Most of this area, however, has been destroyed by the work of the Wagner Stone Company, and when studied on September 19, 1914, only a small portion of it remained, which was located about east of the crusher and on both the east and west sides of the quarry track running from the crusher around to the new part of the quarry to the northwest. This ripple-marked

layer is in the upper part of the Columbus limestone, the western continuation of the Onondaga limestone of New York.

In general, the crests of the ripple-marks which remained in September, 1914, run N. about 20° W., but those farthest to the west run N. about 25° W. Occasionally two will run together and, in one case at least, then diverge again. The crests of those studied vary from 22, 24, 25 to 26 inches apart, the greater number of them being about 2 feet apart. Mr. Ransom reported those shown in the half-tones as "being 3 to 4 feet from crest to crest."[1] In the somewhat worn surface of the layer it is difficult to distinguish any particular difference in the angle of slope of the two sides; although, perhaps, some of the ripple-marks west of the quarry track are a little steeper on the southwest side, with a little longer slope on the northeast side. The troughs of these ripple-marks are rather shallow, although the exact depth was not determined. Figs. 4, 5, and 6 are from photographs, furnished by Mr. DeLos C. Ransom, of the floor of the old (Schoepfle) quarry, showing the ripple-marks as they formerly appeared before this layer was mostly destroyed by the extensive work of the Wagner Stone Company. Mr. Ransom has stated that in Figs. 4 and 5 the camera was pointed toward the southeast and parallel to the direction of the ripple-marks. In Fig. 6 the direction across the ripple-marks is toward the northeast, at right angles to Fig. 4, and the crests are three or four feet apart.[2] Mr. Ransom has written several times concerning these ripple-marks, and the following quotation is from one of his letters:

> Now such ripple-marks 3 or 4 feet wide as are in limestone must have been constructed in water 50 to 100 feet deep and waves of immense size in the ancient comparatively shallow and wide sea when our limestones were laid down. "Ripple-marks" hardly expresses or describes these large parallel stone *waves*. They are perpendicular to the direction of the wind, hence aeons ago winds were as now largely S.W. and N.E. and hence the poles of the earth have not changed since.[3]

[1] Letters of January 25, 1902, and October 28, 1903.

[2] Letter of September 25, 1915.

[3] Letter of October 28, 1903.

On September 19, 1914, a considerable area in the new (northwest) part of the quarry had been stripped of soil and this upper surface of the limestone was beautifully glaciated. It was all worn smooth and marked with striae of various degrees of strength; but part of them are rather strong. The direction of the striae was determined at different places on this surface and in all cases they ran N. 100° W. (W. 10° S.) and N. 80° E. (E. 10° N.).

THE RELATIONSHIPS OF THE OLENTANGY SHALE AND ASSOCIATED DEVONIAN DEPOSITS OF NORTHERN OHIO[1]

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In the flat glaciated region to the south and east of Sandusky there are few outcrops of the older rocks. The drainage is mostly by small, weak streams which have not yet had time to erode extensive valleys, and railroads have not been compelled to cut deeply in order to establish their grades. About seven miles south of Sandusky, however, where the land is a little higher than in the city and the mantle rock is exceedingly thin, some of the creeks have exposed small sections of bedrock which are somewhat exaggerated by a considerable local dip. Two of the more important of these are to be found along Plum and Pipe creeks. These sections have been discussed elsewhere,[2] but a recent study of the region has added some valuable facts to those formerly given and has made it possible to correlate this Ohio Hamilton with the Devonian deposits of the same age to the north of Lake Erie.

Plum Creek heads about nine miles southeast of Sandusky and flows, in a general northerly direction, to the lake. At a point about two miles east-northeast of Prout station, on the Baltimore & Ohio Railroad, it cuts into Huron shale, and a little farther north into the Hamilton beds, exposing the following section:

SECTION OF THE HAMILTON ROCKS AND HURON SHALE ALONG PLUM CREEK

	Thickness Ft.	In.
Huron Shale		
12. Shale, bituminous, black	4	0
Widder Beds		
11. Prout or Encrinal limestone. A very hard siliceous blue limestone containing a little chert and much pyrite. Silicified corals and crinoid stems are abundant, the latter especially in the middle layers	8	10

[1] Published with the permission of the Deputy Minister of Mines, Ottawa, Canada.

[2] *Geological Survey of Ohio, Bulletin No. 10*, 4th Series, 1909, pp. 119–22, Pls. VIII and IX.

FAUNA

Favosites billingsi, Zaphrentis prolifica, Fenestella sp., *Atrypa reticularis, Spirifer* sp., *Stropheodonta perplana*

Olentangy Shale

10.	Covered interval	6	0
9.	Limestone, soft, blue, very fossiliferous	0	6

FAUNA

Autodetus lindstroemi, Spirorbis angulatus, Streblotrypa hamiltonensis, Fistulipora corrugatus ?, Hederella canadensis, Trematospira sp., *Chonetes deflectus, Crania hamiltonensis, Leiorhynchus kelloggi, Leiorhynchus laura, Rhipidomella cyclas, Sprifer mucronatus, Stropheodonta demissa, Stropheodonta concava, Actinopteria boydi, Aviculopecten fasciculatus, Glosseletina triquetra, Leiopteri rafinesquii, Microdon bellistriatus, Modiomorpha subalata, Mytalarca oviforme, Pterinea flabellum, Pterinopecten vertumnus, Schizodus appressus, Tellinopsis subemarginata, Bembexia sulcomarginata, Cyrtonella mitella, Pleurotomaria capillaria, Orthoceras* sp., *Bairdia devonica, Bollia* sp., *Bythocypris indianensis, Primitiopsis punctulifera, Phacops rana,* Fish plates

8.	Shale, argillaceous, soft, blue	3	6

FAUNA

Chonetes deflectus, Chonetes setigerus, Crania crenistriata, Leiorhynchus kelloggi, Spirifer mucronatus, Styliolina fissurella, Bythocypris indianensis

7.	Limestone, quite hard, blue	0	6

FAUNA

Cystodictya hamiltonensis, Trematopora sp., *Chonetes deflectus, Leiorhynchus kelloggi, Leiorhynchus laura, Spirifer mucronatus, Actinopteria boydi, Platyceras erectum, Phacops rana*

6.	Shale, soft, blue	5	0

FAUNA

Chonetes deflectus, Bythocypris indianensis

5.	Limestone, blue, lower part shale, very fossiliferous	0	6

FAUNA

Ambocoelia umbonata, Chonetes deflectus, Leiorhynchus kelloggi, Stropheodonta demissa, Cypricardinia indenta, Glyptocardia speciosa, Grammysia arcuata, Grammysia bellatula, Grammysia bisulcata, Grammysia constricta, Modiomorphia subalata, Nucula corbuliformis, Nuculites oblongatus, Nuculites triqueter, Nyassa recta, Pholadella radiata, Schizodus appressus, Bellerophon lyra,

Pleurotomaria planodorsalis, Pleurotomaria rotalia, Orthoceras sp., *Bairdia devonica, Barchilina* sp., *Bollia* sp., *Primitiopsis punctulifera, Bythocypris punctatus, Phacops rana,* Fish plate

4. Shale, argillaceous, soft, blue. This shale contains numerous small pyrite concretions, some of which are beautifully twinned crystals. The fossils are probably rare in most of it and appear to be in streaks or layers. Mostly covered ..... 10± 0

FAUNA

Orbignyella monticula, Leiorhynchus laura, Spirifer mucronatus, Athyris spiriferoides

3. Shale, blue, with pyritized fossils ..... 0 6±

FAUNA (PYRITIZED)

Leiorhynchus sp., *Leda rostellata, Nuculites triqueter, Bactrites arkonense, Tornoceras uniangulare*

2. Shale, blue. Fossils rather abundant ..... 3± 0

FAUNA

Alveolites monroei, Aulopora cornuta, Aulopora serpens, Ceratopora rugosa, Zaphrentis prolifica, Spirorbis omphalodes, Acanthoclema hamiltonense, Ascodictyon stellatum, Batostomella obliqua, Fistulipora involvens, Fistulipora spinulifera, Hederella canadensis, Hederella filiformis, Heteronema monroei, Orbignyella monticula, Orbignyella tenera, Athyris spiriferoides, Chonetes coronatus, Chonetes deflectus, Crania hamiltoniae, Cryptonella planirostra, Cyrtina hamiltonensis, Leiorhynchus kelloggi, Philidostrophia iowaensis, Spirifer mucronatus, Stropheodonta demissa Tropidoleptus carinatus, Styliolina fissurella, Bairdia devonica, Primitiopsis punctulifera

1. Shale, soft blue, with some flat calcareous concretions. Fossils rare ..... 5± 0

The other important Ohio outcrop is along the south branch of Pipe Creek, one-fourth mile east of Bloomville and about three miles west of the one just given on Plum Creek. At that point the Prout limestone has been quarried to a limited extent, and is therefore well exposed, although the beds of shale below are pretty well sodded over.

SECTION OF THE HAMILTON BEDS ALONG SOUTH BRANCH OF PIPE CREEK

Widder Beds		Thickness Ft.	In.
4.	Prout or Encrinal limestone. An impure blue limestone some layers of which are very crinoidal and the upper one containing rather numerous corals	9	0

FAUNA

Baryphyllum verneuilanum, Cladopora canadensis, Cladapora roemeri, Cystiphyllum vesiculosum, Favosites alpenaensis, Favosites billingsi, Favosites placenta, Favosites radiciformis, Favosites turbinatus, Heliophyllum halli, Syringopora intermedia, Zaphrentis prolifica, Polypora; sp., *Atrypa reticularis, Athyris vittata, Chonetes mucronatus, Chonetes scitulus, Rhipidomella vanuxemi, Schizophoria striatula, Spirifer audaculus macronotus, Spirifer mucronatus, Stropheodonta demissa, Platyceras erectum, Phacops rana*

Olentangy Shale

3. Shale, blue, alternating with blue argillaceous limestone; very poorly exposed but weathered blocks of the limestone lie on the steep bank and numerous fossils have weathered out of the softer layers..... 15± 0

FAUNA

Ceratopora rugosa, Zaphrentis prolifica, Spirorbis, angulatus, Spirorbis omphalodes, Acanthoclema hamiltonensis, Batostomella obliqua, Botryllopora socialis, Cystodictya hamiltonesnsis, Fistulipora spinulifera, Hederella filiformis, Orbignyella monticula, Polypora sp., *Ambocoelia umbonata, Atrypa reticularis, Chonetes deflectus, Chonetes scitulus, Crania hamiltonensis, Cryptonella planirostra, Leiorhynchus laura, Rhipodomella cyclas, Schizophoria striatula, Spirifer mucronatus, Stropheodonta demissa,* Fish plate

2. Shale, marly, blue, badly weathered and soil-covered..... 10± 0
1. Shale, blue, with disk-like blue limestone concretions..... 5± 0

The lower part of the shales in these sections is apparently not very fossiliferous. The same is usually true of the Lower Hamilton of Ontario and in many places of the similar deposits in New York. This is probably even more characteristic of the Olentangy shale in central Ohio. However, at Delaware, Winchell's type section of the Olentangy, a few poorly preserved fossils[1] were found which, although only given generic identification, are believed to be identical with others found in the shales of the Sandusky region. It was at Delaware also that the crinoid bed was found in the Olentangy shale—a lens corresponding in every way with the thin lenses of crinoidal limestone common in the lower shales of

[1] *Geological Survey of Ohio, Bulletin No. 10,* 4th series, 1909, p. 89.

the Hamilton beds exposed along Aux Sable River in Ontario. The general make-up, appearance, and physical properties of the shale below the Prout limetsone and the Olentangy shale are the same (Figs. 1, 2, and 3). Moreover, the Delaware limestone, which underlies this deposit at Delaware and at Sandusky, carries the

FIG. 1.—A weathered bank of fossiliferous Olentangy shale showing one of the common calcareous layers in this shale along Plum Creek, near Prout station.

FIG. 2.—A bank of Olentangy shale along the Olentangy River at Delaware, Ohio. The limestone disks in this bank contain an occasional fragmentary fossil. The lens of crinoidal limestone was found at this locality. This is Winchell's type locality for the Olentangy shale and shows its marked contrast to the Ohio or even to the blue bands occurring in the middle portion of the latter.

same fauna at both places and extends northward into Ontario. Whitfield found the lower part of the Delaware to be the western extension of the Marcellus shale, to which he considered it to be in part equivalent.[1] Wherever the Delaware limestone becomes

[1] R. P. Whitfield, *Proceedings of the American Association for the Advancement of Science*, XXVIII (1879), 298.

especially shaly, as is often the case, the fauna tends to revert to that of the more typical Marcellus, so that these forms are not limited to the basal portion. But the occurrence in it of certain fossil forms more characteristic of the true Hamilton beds of New York than of the Marcellus of that region has led to the use of Marcellus-Hamilton or Lower Hamilton for the Delaware. In this use of the Hamilton, it is the older and broader sense of that term, rather than the restricted present usage, that was intended. It would more properly be called the lower Erian. The Olentangy

FIG. 3.—A bank of Olentangy shale downstream a short distance from the one illustrated in Fig. 2.

shale is overlaid by the Ohio shale in the central part of the state and by the Huron or lower Ohio shale at Sandusky. The stratigraphic position of the blue shale in question, therefore, suggests the same correlation that has been made on the meager fauna and the lithological similarity. When it is recalled that the regions in question lie within the same Devonian basin and that the deposits are a continuation of the same general line of Devonian outcrops, traceable by well-records in the covered interval between, this relationship seems worthy of consideration.

The relation of the Sandusky deposit to the Hamilton beds of Ontario is much more easily determined. In a memoir on the Devonian of southwestern Ontario, which was recently published by the Geological Survey of Canada, the correlation of the shale below the Prout limestone with the Olentangy has been adopted, and the

Hamilton beds have been divided, in descending order, into the Ipperwash limestone, the Petrola shale, the Widder beds, and the Olentangy shale. In the sections at Arkona, Lambton County, the two lower stages are well exposed. At no place in the province is the bottom of the Olentangy shale exposed, although well-records indicate that it rests directly upon the Delaware limestone. This latter formation is well shown in the excellent outcrops at St. Mary's and at several places in the vicinity of Brussels and Goderich. In the following section of the Hamilton beds in Rock Glen at Arkona, only the fauna of the Encrinal limestone and of the beds below are given, since the subsequent comparison is made with those portions of the section only.[1]

SECTION OF THE HAMILTON ROCKS AT ARKONA, ONTARIO

Widder Beds	Thickness Ft.	In.
11. Soil and drift	15	0
10. Limestone, argillaceous, massive, blue, partly cystalline, alternating with thin layers of shale. These beds form the falls at the old mill	10	8
9. Shale, soft, blue, with calcareous nodules or concretions	8	4
8. Limestone, argillaceous, blue	1	6
7. Shale, usually soft, blue, but some layers harder and more massive	17	5
6. Shale and shaly blue limestone	7	0
5. Coral zone. A decomposed blue or gray shale, often an impure shaly limestone, filled with corals	3	6
4. Encrinal limestone. A hard, pyritiferous, bluish-gray limestone which is full of crinoid segments, coral fragments, and other fossils. It includes some brownish shale near the base	2	4

FAUNA

Aulopora serpens, Ceratopora dichotoma, Cladopora canadensis, Cladopora roemeri, Craspedophyllum archiaci, Cystiphyllum vesiculosum, Favosites alpenaensis, Favosites placentus, Favosites turbinatus, Heliophyllum halli, Syringopora intermedia, Syringopora nobilis, Trachypora elegantula, Zaphrentis prolifica, Dolatocrinus liratus, Hederella filiformis, Streblotrypa hamiltonensis, Taeniopora exigua, Ambocoelia umbonata, Atrypa reticularis, Athyris vittata, Chonetes coronatus, Chonetes lepidus, Delthyris

[1] The fauna of the other beds may be found listed in the *Geological Survey of Canada Memoir* (No. 34, p. 164), on the Devonian of southwestern Ontario.

sculptilis, Leiorhynchus laura, Pholidops hamiltoniae, Pholidostrophia iowaensis, Productella productoides, Rhipidomella penelope, Rhipidomella vanuxemi, Schuchertella perversus, Spirifer divaricatus, Spirifer mucronatus, Stropheodonta concava, Stropheodonta demissa, Stropheodonta perplana, Pterinea flabellum, Platyceras erectum, Tentaculites bellulus, Phacops rana

Olentangy Shale

3. Shale, soft, gritless, blue, containing few fossils except in certain streaks or layers..... 19 0

FAUNA

Microcyclas discus, Arthracantha punctobranchiata, Chonetes lepidus, Pholidostrophia iowaensis, Platyceras erectum

2. Shale, soft, gritless, blue, with a few thin lenses of very fossiliferous crinoidal limestone. These beds include a thin zone in which the fossils are small and always pyritized..... 6 0

FAUNA (PYRITIZED)

Leda rostellata, Nucula lirata, Nuculites triqueter, Paracyclas lirata, Bactrites arkonensis, Tornoceras uniangulare

FAUNA (NON-PYRITIZED)

Arthracantha punctobranchiata, Gennaeocrinus arkonensis Palaeaster eucharis, Chonetes deflectus, Chonetes lepidus, Chonetes scitulus, Cyrtina hamiltonensis, Parazyga hirsuta, Productella spinulicosta, Schuchertella perversus, Spirifer mucronatus, Actinopteria boydi, Glypodesma erectum, Bellerophon triliratus, Platyceras erectum, Platyceras rarispinosum, Platyceras subspinosum, Pleurotomaria delicatula, Styliolina fissurella, Tentaculites attenuatus, Tentaculites bellulus, Primitiopsis punctulifera, Phacops rana

1. Covered interval to the level of the Ausable River..... 10 0

The most important point of similarity between the Ohio and Ontario sections is to be found in the fauna of the thin layer about 25 feet below the base of the Prout limestone, and at a similar distance below the Encrinal limestone of Ontario. In both cases the fossils are pyritized and of small size. Although the fauna of this layer is somewhat more limited in Ohio, the four species that have been found in it are identical with those of the similarly located layer of the Arkona section. At no other horizon has this fauna been found in Ohio, and three of the species have not been

found outside of it in Ontario, and even the fourth but sparingly. It seems certain, therefore, that this is the same horizon in both cases. From the prominence of *Bactrites arkonensis* in this layer at Arkona and Sandusky, it may be termed the Bactrites horizon.

The question next arises as to the relationship of the beds above the Bactrites horizon. In the Sandusky region the fossils of this portion of the formation seem to be more abundant in certain streaks or beds. To a limited extent the same is true of the shales below the Encrinal limestone in Ontario, but there the great body

FIG. 4.—The Prout or Encrinal limestone overlain by the Huron shale at Slate Cut along the Lake Shore and Michigan Southern Railway three miles east of Sandusky, Ohio.

of the deposit between the Bactrites layer and the Encrinal limestone is very sparingly fossiliferous. The Encrinal limestone may be described as several layers of a hard, pyritiferous, bluish-gray limestone which is often full of crinoid fragments—a description which fits equally well the Prout limestone (Fig. 4) in the sections here under consideration and especially the middle layers at Bloomingville. Along Eighteen Mile Creek, New York, one of the important fossils of the Encrinal limestone is *Delthyris sculptilis*. Grabau says: "This species is entirely restricted in this region to the Encrinal limestone, and may be regarded as the typical fossil of the fauna."[1] This is also the case in Ontario and probably led Shimer and Grabau to correlate the limestone in Ontario with

[1] *Bulletin of the Buffalo Society of Natural Science*, Vol. VI (1898), 32.

the similar one in western New York,[1] although many other forms are also common to the Encrinal limestone of the two regions.

The fossils in the beds immediately below the Prout limestone are more abundant than in the shale just below the Encrinal limestone of Ontario. In this respect the northern Ohio deposit shows more decided relationship to the western New York section. In fact, the upper part of it includes a portion of the fauna of the "Demissa bed," although it lacks *Spirifer granulosus* and some of the other prominent forms. However, this suggested relationship with the New York section is not fully substantiated.

In addition to the marked lithological similarity and stratigraphic relation of the Prout and Encrinal limestones, over 75 per cent of the fauna of the Prout limestone also appears in the Encrinal limestone of Ontario, and the upper layers contain many of the corals of the coral zone at Arkona, Ontario. It seems reasonably certain, therefore, that the Prout limestone is the Ohio representative of the Encrinal limestone to the north and perhaps to the east as well.

At Kettle Point, Ontario, the Devonian black shale rests upon a limestone of the Hamilton which lies about 150 feet above the Encrinal limestone, and well-records[2] show that this is the usual succession of beds in Lambton County, Ontario. In Middlesex and Kent counties, which lie to the south of Lambton, this limestone is sometimes present, but at other places is wanting,[3] as might be the case where erosion has taken place prior to the deposition of the black shale. The Huron, or basal portion of the Ohio, lies directly upon the Prout limestone at Sandusky. It therefore either represents the upper Hamilton shale and limestone of Ontario, or these deposits are wanting in northern Ohio and the Huron shale rests unconformably on the Encrinal limestone. On the basis of the fossils and the occurrence of spheroidal concretions in both deposits, Kindle has correlated the black shale at Kettle Point, Ontario, with the Huron shale of northern Ohio.[4] If this correlation

[1] *Bulletin of the Geological Society of America*, Vol. XIII (1902), 164, 166.

[2] H. P. H. Brumell, *Geological Survey of Canada, Ann. Rept.*, V, Part Q (1892), 61–70.

[3] *Ibid.*, pp. 52, 73, 74.

[4] *Geological Survey of Canada, Summary Report for 1912* (1914), pp. 287, 288.

is correct, as seems probable, the Huron shale does not represent the Upper Hamilton, but rests unconformably on the Prout or Encrinal limestone.

Mr. Allen R. Stuckey, who has drilled numerous wells in Crawford and adjoining counties, reports that at Bucyrus the drift ranges from 55 to 80 feet in thickness. Under this is 35 to 200 feet of black shale, which is usually succeeded below by about 10 feet of gray shale, so tough and sticky that it is difficult to drill. This gray shale immediately overlies the limestone, but in a few wells it has been found to be absent where the black shale rests

FIG. 5.—The Olentangy-Ohio shale contact at "Dripping Rock," near Liberty Church, Delaware County, Ohio. Here again there is an undulating contact.

directly upon the limestone. In the eastern part of this county, 30 feet of the gray shale is found at many places. It is evident, therefore, that in Crawford County the Olentangy shale is even more variable in thickness than it is in central Ohio and that the Prout limestone of the Sandusky region has disappeared. At "Dripping Rock" (Fig. 5), in Delaware County, where the Prout limestone is wanting and the Olentangy shale is only about 31 feet in thickness, the contact between it and the overlying Ohio shale is most marked and slightly undulating. The contact is equally marked at High Banks, near the Franklin-Delaware county line, and again in the town of Delaware (Fig. 6). At this latter place the basal Ohio shale is somewhat arenaceous. Near the Ohio River, at Kinkead Springs, Pike County, the Ohio extends down to the Silurian limestone and is firmly welded to it.

Southward from Kettle Point, Ontario, therefore, the Huron or lower portion of the Ohio shale rests on older and older beds to which its relationship must be that of unconformity (disconformity). This relation is not strikingly perceptible at any one place, but in southern Ohio the time interval between the Silurian and Devonian strata, which are in contact, is enormous. When it is recalled that the first effect of running water on a newly uplifted land surface is to roughen it, and that continued erosion tends to produce planeness, it is clear that, where little or no folding or tilting of the stratified rocks has taken place, slight (apparent) unconformities are likely to

FIG. 6.—The sharp and slightly undulating contact between the Ohio and the Olentangy shales in the clay pit at Delaware, Ohio.

represent great intervals of time, while conspicuous ones may stand for shorter intervals. Or, in other words, the greater the time interval which is represented by an erosional unconformity (disconformity) in undisturbed strata, the more evasive it is likely to be. This is probably one of the chief reasons for the marked differences in the interpretation of sections where such gaps in sedimentation occur. With the Hamilton beds at Sandusky and in central Ohio resting on the Delaware limestone (Lower Erian) and overlaid unconformably by the Ohio shale in both places, the advisability of calling the soft marly beds to the south of Sandusky, Olentangy shale seems to be justified, even though the faunal evidence may not be as conclusive as could be desired.

EVOLUTION OF THE BASAL PLATES IN MONOCYCLIC CRINOIDEA CAMERATA. I

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PART I

INTRODUCTION

Most students of fossil crinoids have been interested in the morphological results of evolution rather than in the morphological processes of evolution and their results, and the description of extinct, fossil crinoids as well as of most living ones has been in general a tabulation of those results. In many cases the tabulation is incomplete, not only because of the rarity and incompleteness of the specimens described, their poor preservation and sometimes poorer preparation, but also because the obscure morphological processes which have given rise to their characteristics are either overlooked or misinterpreted. The greatest difficulty in establishing a natural classification lies in the fact that processes giving rise to morphological characteristics must be known before a correct interpretation and classification can be made. From necessity paleontologists are familiar with the obscurity of processes. The ontogeny of the fossil crinoid is only partially revealed, and that mostly in the phylogenetic succession, for the delicately constructed embryos are ill-adapted for preservation, and comparatively few immature individuals have been preserved. The complete embryonic and larval development of modern crinoids is known only in one highly specialized genus, *Antedon;* the larval stages, however, are partially known in four other genera, *Promacocrinus*, *Thaumatocrinus*, *Comactinia*, and *Hathrometra*.

Various phases of the evolutional changes in the basal plates of crinoids have been considered by both paleontologists and zoölogists. The relation of these plates to the column, their modification by the anal plate, and their characteristic decrease in number and size with the passage of geologic time attracted attention long before the importance of tegminal structure was realized,[1] and some interesting though unsuccessful attempts have been made to use basals as a foundation for classification.[2] Such artificial classifications have been swept away, but the fact remains that the changes of each plate and system of plates, as they have passed through the varying stages of evolution, must have classificatory value. When, where, and from what the monocyclic Crinoidea originated are questions of great importance, yet not of special import for the subject as herein discussed. The fact that monocyclic crinoids have existed, that their basal plates exhibit a series of remarkable changes, and that certain features in their phylogeny throw much light upon the character of the changes and their succession, is sufficient for present purposes. The process by which these changes came about is the problem to be considered here.

In this paper no attempt at reclassification will be made, but the changes exhibited by the basal plates will be reviewed, the nature of these changes studied, and suggestions arising from these studies will be applied to certain theories of descent that have arisen from similar studies made by others.

ACKNOWLEDGMENTS

The writer desires to express his sincere appreciation to Professor Stuart Weller, of the University of Chicago; Mr. Frank Springer, Mr. Austin Hobart Clark, Dr. E. O. Ulrich, and Dr. R. S. Bassler, of the United States National Museum; and to Professor R. A. Budington, Dr. Charles G. Rogers, and Dr. Maynard M. Metcalf, of Oberlin College, for the material assistance given by them in the use of specimens and literature, and for a broad view of the

[1] Ref. 38. (The reference figure is the number assigned to the work cited in the Bibliography.)

[2] Ref. 2; ref. 22.

processes operative in the growth and modification of many groups of invertebrates.

To Professor Weller, Mr. Springer, and Mr. Clark the writer is especially indebted for their many kindnesses, their helpful advice, and the privilege of freely studying their collections of fossil and recent crinoids.

REVIEW OF WACHSMUTH AND SPRINGER'S THEORY OF BASAL PLATE EVOLUTION

While various phases of basal plate evolution have been touched upon by numerous writers, the discussion by Wachsmuth and Springer[1] is the only one in which a general treatment of the subject has been undertaken, and, in order that the reader may have their theory clearly in mind before going farther, it will be quoted in substance.

The base of a monocyclic crinoid is composed of a single cycle of plates, termed the basal plates, lying at the proximal end of the cup, between the stem and the first plates of the radial series. This plate cycle was primarily composed of five separate plates, but, by anchylosis or the union of two or more members, they were reduced from five plates to four, three, two, or one. The first monocyclic crinoids had five basals.

Before the close of the Lower Silurian (Ordovician) there appeared two monocyclic genera with four basals, both having a special anal plate interposed between the radial. The quadripartite base reached its culmination in the Upper Silurian (Silurian), and disappeared before the close of the Devonian. The earliest genera with a tripartite base occur in the Upper Silurian; some of them have an anal plate, and others not. When that plate is represented, the basals are of equal size; when absent, two of the basals are equal, and the third about half smaller. The two forms continue to exist side by side to the end of the St. Louis group of the Carboniferous (Mississippian) when both became extinct. The bipartite base is restricted to the Carboniferous (Mississippian and Pennsylvanian). It occurs from the Kinderhook group up to the Coal Measures, but is found only among genera with a large[2] anal plate.

[1] Ref. 39, pp. 52–68.

[2] The exact meaning of the statement that the bipartite base is found only among genera with a large anal plate is doubtful, as *Pterotocrinus*, a genus with a hexagonal bipartite base, usually has, in proportion to the size of its basals and radials, the

It is evident from these observations that the number of basals was gradually reduced in Paleozoic times, and that in the Camerata the anal plate was introduced after the quadripartite base had made its appearance. It will now be shown that this diminution of number was the result of fusion of two or more of the five original plates, and that by the introduction of the anal plate the base underwent further modifications. The manner in which the modifications in the number of basals were effected may be best understood by reference to the diagrams on Table A. [This table is photographically reproduced as Fig. 1 of this article.]

Looking at these diagrams, the transmutation in the Camerata from five basals to a less number is readily understood among genera in which the anal plate is wanting. When the base is quadripartite, it is invariably the two anterior plates of the elementary five which are consolidated (2). In the tripartite base there is a fusion of the posterior with the left postero-lateral basal, and another between the right posterior and the adjoining antero-lateral plate (3). The figure shows that a bisection of the two larger plates will reproduce the original five pieces, interradially disposed.

The case is not so simple in genera with an anal plate, where the form of the basal disk is changed from pentagonal to hexagonal (4), as a bisection of

smallest anal plate now known among Camerata in which the anal plate is in apposition with the base. See Pl. III, No. 11, and Ref. 39, Pl. 79, Figs. 2–9.

When preparing figures for this paper from specimens in Mr. Springer's collection, with his permission, I overlooked the fact that the dorsal cup of this species had never been described or figured. As to this, Mr. Springer has furnished me the following note:

"When proposing the species *Pterotocrinus coronarius* (*Geology of Kentucky*, III, 476, Pl. I, Figs 1*a*, *b*) Lyon described and figured only the tegmen with the ponderous wing plates, as did Wachsmuth and Springer after him (*N.H. Crin. Cam.*, p. 795). While this work was in press I discovered in the Museum of Comparative Zoölogy at Harvard a lead cast of what was apparently the same specimen, with the dorsal cup attached, which fact I mentioned in a footnote on the page cited. When I acquired in 1903 the collection of the late Col. Sidney S. Lyon, I found associated with the tegmen constituting the published type the dorsal cup reproduced in the cast; the two parts were separated, but I have again united them. It is probable that they belong to the same specimen, and the fact that they pertain to the same species is proved beyond question by another specimen from the same locality having the same dorsal cup with one of the wing plates attached. The species is remarkable, not only for its extraordinary wing plates, but also for the construction of the dorsal cup, in which the basal plates are very small and flat, while the radials are of enormous size, larger than all the other plates of the cup combined; this being the reverse of the structures in *Pt. capitalis* and all other known species of the genus. It occurs in the Birdsville formation of the Kaskaskia group, in Crittenden County, Kentucky, where it is extremely rare; and also in the Renault formation in Monroe County, Illinois, from which region a fragmentary specimen was described by Hall (*Geol. Iowa*, II, 689, Pl. XXV, Fig. 7) under the name *Dichocrinus protuberans*."

the larger plates would produce six plates instead of five. This difficulty, however, is overcome if we consider that the introduction of the anal plate into the ring of radials necessitated corresponding modifications among the basals, as otherwise these plates would lose their interradial position. It

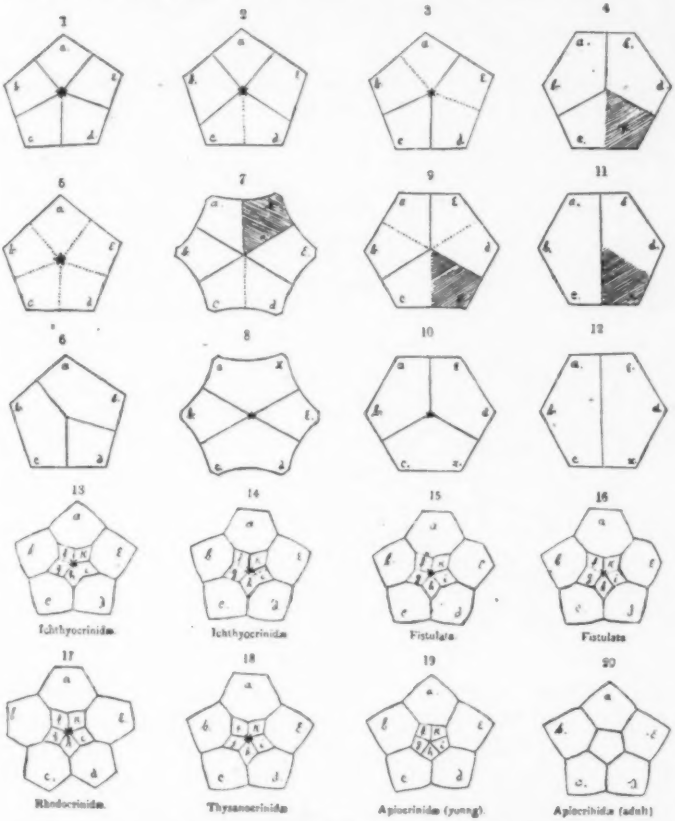

FIG. 1.—Diagrams illustrating the evolution of the basals and infrabasals: all figures represent the anal side at the top; *a*=posterior basal; *b* and *e*=postero-lateral basals; *c* and *d*=anterior basals; *f*, *g*, *h*, *i*, *k*=infrabasals.

required either the introduction of a basi-anal plate, or an increase in the size of the original pieces. That the latter occurred among the Camerata is clearly shown by the diagrams, and the evidence leaves no doubt at what part of the base the extra width was inserted.

Taking first the quadripartite base, and comparing 2 of the diagrams with 8—one pentangular, the other hexangular—we find that in the latter the posterior basal has doubled in size (7), without materially changing the orientation of the plates, or disturbing their general arrangement. . . . .

In the tripartite base the change was accomplished in a different way. There *x* is added to plate *c* (9 and 10), and plates *ab* and *ed* have coalesced, and hold relatively the same position as in 3.

The bipartite base is probably derived from the tripartite (4), which preceded it in time, and *x*, which in the latter constituted a part of *c*, is united with *de*, and *ab* with *c* (11 and 12).

Now taking up 7 and eliminating *x*, so that the side of plate *a* rests against the plate *e*, we obtain 2, and by a similar procedure we are enabled to transform 9 into 3. The hexagonal base is thus restored to its primitive pentagonal form without disturbing the orientation of any plate, compound or simple.

This theory was thought by Wachsmuth and Springer to have been confirmed by an abnormal example of *Teleiocrinus umbrosus* n which the anal plate was wanting.

Teleiocrinus umbrosus has normally three equal basals, but in this specimen the basal plate to the left of the anterior ray is reduced to one-half its normal size, leaving the basal disk exactly like that of forms which are normally without the anal plate.

It is very remarkable that while in all crinoids with an unequally tripartite, monocyclic base, the smaller plate is located to the *left* of the anterior radial, this plate in the base of the blastoids lies invariably to the *right* (6).

In the discussion of the changes from the pentagonal, five-basal form to the hexagonal, four-basal form, it is stated that the enlargement of the posterior basal took place upon the right side of that plate, but no evidence is submitted for this statement. Why could not the enlargement have taken place as well upon the left side, or by symmetrical development upon both sides of the posterior basal? The statement that "the evidence leaves no doubt at what part of the base the extra width was inserted" is not sufficient, and it in itself creates a doubt. Again we are told that "the introduction of the anal into the ring of radials necessitated corresponding modifications among the basals, as otherwise these plates would lose their inter-radial position."[1] However, in the discussion of the basals in dicyclic crinoids the statement is made that "the introduction of the anal plate into the ring of

[1] Ref. 39, p. 59.

radials did not affect the basals of dicyclic crinoids" in the same manner as in the monocyclic. While in the latter, when the plate is represented, the orientation of the basals is slightly disturbed, in the dicyclic forms it remains unaltered. The anal plate of the latter rests invariably upon the trunkated upper face of the posterior basal; while in monocyclic crinoids it is supported by the basals *a* and *e* (Nos. 10 and 12), or occasionally by *a* and *x* (No. 8).

This statement leads one to believe that no widening of the posterior basal took place upon the introduction of the anal plate in the dicyclic form, but Nos. 15–18 in Fig. 1 show a decided widening of that plate. Overlooking this inconsistency and the fact that trunkation of the posterior basal is in itself an alteration, we are still unenlightened as to why alteration is demanded in the one case and not in the other, as no explanation of an alternative phenomenon is given. Neither is any reason given, other than the position of sutures, for the markedly different positions of enlargement in basal plates of the four-, three-, and two-basal hexagonal forms. By reading between the lines one is able to supply various explanations, yet they are not the explanations of the writers, nor what is needed and demanded by the conditions of the problem. Furthermore, no reasons nor illustrations are given showing why the abnormal specimen of *Teleiocrinus umbrosus*, by which the theory was apparently confirmed, was oriented with the smaller basal in the left anterior interray. The questions in the writer's mind are: Why should the stimulus of enlarging the anal area in the quadripartite form cause enlargement of the right side of the posterior basal and not of the left or of both sides as well? Why should the same stimulus in a dicyclic crinoid have no effect upon the adjacent basal plates? Why should the same stimulus cause the enlargement of the left anterior basal in the equibasaled, tripartite form, and of the left side of the right anterior basal in the equibasaled, bipartite form, derived therefrom? What was the nature of the change in shifting factor *x* from basal *c* to basal *d*? How could such changes take place without disturbing the orientation of any plate, compound or simple? What were the reasons for the orientation assigned to the abnormal specimen of *Teleiocrinus umbrosus*? These questions have led the writer to investigate

the evolution of the basal plates in the monocyclic Crinoidea, and the result of this investigation will be stated in the latter part of this study.

REVIEW OF CERTAIN PHYLOGENETIC CHARACTERISTICS IN MONOCYCLIC CAMERATA

In this review the phylogenetic characteristics of the various groups of monocyclic Camerata will be considered, for it is in this order that the succession is better understood and that the evolution of the basal plates is the most complex. There exist in this order two great groups, separated structurally but not phylogenetically according to the outline of the basal cup, and therefore according to the presence or absence of an anal plate in contact with and trunkating the posterior basal. The first of these groups possesses an anal plate in apposition with the posterior basal, and has in consequence a hexagonal basal. The second group, in which plates of the anal series are either present or absent but not in contact with the posterior basal, has a pentagonal base. In considering these facts, questions of descent and relationship necessarily arise.

In the ontogenetic development of the external skeleton in the living *Antedon*[1] so many of the phylogenetic steps found in fossil crinoids are illustrated, that it may well be looked upon as a key to their methods of development and perhaps to their interrelationships. Leaving out of consideration the earlier embryo-logical stages, let us follow in detail the methods of plate intercalation and development after the formation and contact of the basal and oral plates (Fig. 2).

About the time of the attachment of the pentacrinoid larva, the basal plates assume a regular, trapezoidal outline, the lower part of each being an acute-angled triangle with its apex distally directed (Fig. 2, No. 1). The sides of the lower triangle are bordered by a somewhat thickened edge of solid, transparent stereom, the presence of which indicates that the plate has received its full proportionate increase in that direction.[2] Even after the plate

[1] *Antedon*, while more highly specialized in its larval development than some of the other modern crinoids, is chosen for comparison with the Camerata because it is the best known of any of the genera in which the larval development has been studied.

[2] Ref. 11, p. 729.

edges are thus defined, the plates steadily increase in size, apparently by interstitial growth.[1] The adjacent borders of the plates, however, do not come into absolute contact, as a thin lamina of sarcode is interposed between them until the sutures are closed by anchylosis. The upper margins of the basals have at this time no distinct border,[2] but are still growing by the process of branching and anastomosis (see p. 501, plate growth).

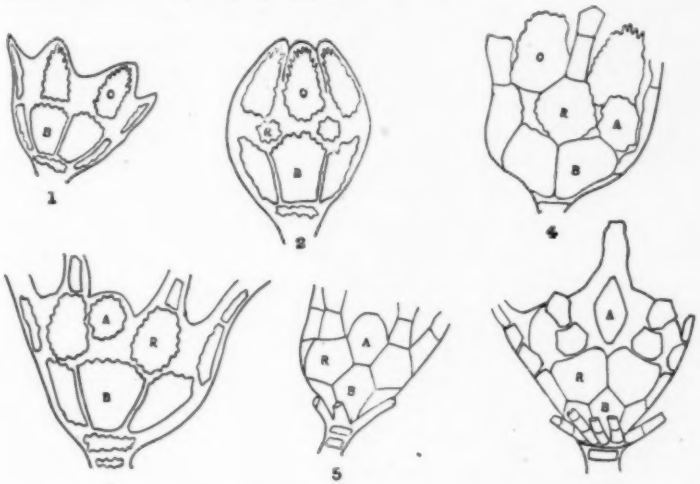

FIG. 2.—Formation of the dorsal cup and migration of the anal plate in *Antedon rosaceus:* 1, 2, after Thomson; 3–5, after Carpenter; 6, original from specimen in Oberlin College Museum; *o*=orals; *b*=basals; *r*=radials; *a*=anal.

Shortly after the fixing of the pentacrinoid and the opening of the cup, a third series of plates, the radials, make their appearance in the space left by the beveling off (absorption) of the adjacent lateral angles of the basals and orals (Fig. 2, No. 2),[3] the beveling being caused apparently by the encroachment of the radials.[4] About the period of the development of the second radials (costals) a forked spicule makes its appearance between the upper parts of the posterior radials. This plate gradually increases in the regular

[1] Interstitial growth: ref. 35, p. 538.

[2] Ref. 11, p. 729, Pl. 41, Fig. 1, *b*.

[3] Ref. 35, p. 539.

[4] Ref. 11, p. 729.

way (see p. 502), until it develops into a round, cubiform plate, the anal plate (Fig. 2, No. 3).[1] The radials, with the anal plate between, now form nearly a complete circle, resting on the basals and separating them completely from the orals.[2] Although greatly enlarged, the radials are still subquadrangular in outline, the proximal angle occupying the enlarged portion of the interbasal suture, and the distal angle, now trunkated, supporting the narrow costals.[3] Considerable space still exists between the adjacent radials, except where they are in apposition with the anal plate (Fig. 2, No. 4), and these spaces are filled only with sarcodic substance.[4] The anal plate from proximal growth now comes into apposition with the posterior basal, and the two are mutually trunkated. Upon further development the radials meet, and their margins assume the finished appearance previously noted in the proximal portion of the basal plates. The posterior radials, especially the right, however, show marked asymmetry, owing to the non-development of the sides adjacent to the anal plate (Fig. 2, No. 5). Growth in the radials does not cease upon their meeting, and as the basals do not now further enlarge, the radials and the anal are forced by contact with each other to extend themselves in an oblique direction, thus enlarging their distal perimeter, and increasing the diameter of the tegmen.

The anal plate by this time has reached its full development and, being more firmly attached to the visceral mass than to the adjacent radials,[5] is gradually lifted out of the cup by the extension of the anal tube. The space left by the withdrawal of the anal is gradually filled by lateral growth from the adjacent radials, which, however, do not immediately come into contact. Before the anal is completely withdrawn from the radial cycle, however, the posterior radials meet below it, and, as withdrawal continues, corresponding and continuous enlargement of the radials fills the re-entrant angle, and gives to the plates their bilaterally symmetrical outline (Fig. 2, No. 6).

About this time a very remarkable change takes place in the tegmen. The oral cycle, like the basal one, does not partake of

[1] Ref. 35, p. 529 (anal).
[2] Ref. 15, p. 314 (radianal).
[3] Ref. 11, p. 729.
[4] Ref. 11, p. 729.
[5] Ref. 11, p. 732.

the pronounced enlargement noted in the radial cycle, its diameter being neither increased by growth of its component parts nor augmented by their separation from one another; but, as the ventral disk expands, the orals become separated from the radials upon which they were previously superimposed and are carried upward and relatively inward and the costals and lower distichals are incorporated into the cup. The space now existing between the radials and orals generally remains as a simple, membranous perisome, traversed by the five ambulacral canals; but, in some specimens of *Antedon rosaceus*,[1] and in other modern crinoids, well-defined groups of interradial plates develop in the angles between the brachials. When these plates appear in the cup they are known as interbrachials, and in the tegmen as interambulacrals. Further tracing of the development of the basals and the orals and consideration of stem formation are not here necessary, although they may at times be referred to in the following discussion.

In tracing the phylogeny of the Batocrinidae and Actinocrinidae, the anal plate is found as a constant characteristic and the base throughout the series is hexagonal. Complete incorporation of the ambulacral grooves has taken place in the tegmen, and the arms are incorporated in the cup up to and often beyond the second distichals. In *Tanocrinus*, a genus probably closely related to the ancestors of the Batocrinidae,[2] five basals are present; the anal plate separates the posterior radials, and is in apposition with and trunkates the posterior basal.

In *Xenocrinus*, *Comprocrinus*, and *Abacocrinus* only four basals are present, the anterior pair being obviously united and somewhat reduced in width. In the other genera of the Batocrinidae and Actinocrinidae there are three equal basals, the basal sutures meeting the antero-lateral radials and the anal plate. Why the third basal suture meets the anal plate will be considered later (Plate III).

The Melocrinidae, while not showing as complex a basal evolution as that shown in the hexagonal Camerata, are interesting in showing the absence of an anal plate in contact with and trunkating the posterior basal, and in some genera an absence of all plates of

[1] Ref. 35, p. 540. [2] Ref. 6, p. 164.

the anal series. The base throughout this family is pentagonal, and the basals number either five, four, three, or one. When five basals are present the basal sutures meet the radials in the normal manner. When four basals are present either the anterior or left anterior suture is missing, and when only three basals are present the sutures meet the anterior, left-anterior, and right-posterior radials.

The Calyptocrinidae have throughout a pentagonal base and only four basal plates, and the anal plates are entirely missing.

In considering these families the question arises as to whether the base has been pentagonal throughout its whole phylogenetic history or whether there has been a hexagonal stage, as in the Batocrinidae and Actinocrinidae.

The Platycrinidae and Hexacrinidae are characterized by having the ambulacral grooves and lower brachial plates but slightly incorporated in the calyx. The orals in the simpler forms are well developed, and the base is either pentagonal or hexagonal. In the Platycrinidae no anals have been positively determined, and the base is pentagonal. Throughout this group there are ordinarily but three basals, five in youth and sometimes but one in age. Two of the basals are large, the third smaller. In the *Hapalocrinus*,[1] the smaller basal is the right-anterior one, and the basal sutures meet the anterior, right-anterior, and the left-posterior radials, as in *Stephanocrinus*. In the other genera of Platycrinidae the left-anterior basal[2] is the smaller, and the basal sutures meet the anterior, left-anterior, and right-posterior radials. In the Hexacrinidae there are usually three, or two, equal basals, sometimes only one.[3] The base is hexagonal and the anal plate well developed. The basal sutures in the three-basal forms meet the antero-lateral radials and the anal plate; in the two-basal forms the sutures meet the anterior radial and the anal plate.

A discussion of the monocyclic Inadunata as a whole cannot now be undertaken, but certain species of Larviformia which in their development illustrate very clearly, even diagrammatically,

[1] Ref. 21, pp. 94–110.

[2] Exceptions are noted on p. 507 in the description of Fig. 5, No. 6.

[3] Ref. 6, p. 158.

some of the slighter morphological changes found in the Camerata will be considered in the discussion of morphological principles.

Having noted the more conspicuous changes through which the basal cup has passed, a detailed study of the processes involved in these may be undertaken.

DETAILED STUDY OF PROCESSES ACTIVE IN PLATE EVOLUTION

The processes active in the evolution of crinoid plates, especially the basals and radials, may be divided into two broadly separated though often co-operating groups: (1) those which do not *necessarily* modify the relation of contact and position of the plates; and (2) those which do modify these relations. The discussion of the first group of processes includes: (*a*) symmetrical growth; (*b*) symmetrical reduction; and (*c*) anchylosis. The second group includes: (*a*) reduction and compensating growth; (*b*) enlargement and compensating reduction; (*c*) plate division; (*d*) plate migration; (*e*) plate interpolation; and (*f*) anchylosis.

1. CHANGES NOT PRIMARILY MODIFYING THE RELATIONS OF PLATE CONTACT AND POSITION

a) *Symmetrical growth.*—Plate growth in the Echinoidea and Crinoidea[1] is due to the deposition, by amebod cells, of crystalline calcium carbonate, or calcium and magnesium carbonate[2] in reticulate pattern in the mesenchyme. Three, or perhaps more, of the ameboid calciferous cells fuse by means of pseudopodia into a plasmodium or reticulate tissue.[3] There the pseudopodia meet, the protoplasm forms a small calcareous nodule (intracellular secretion, according to Theel; extracellular, according to Semon), which gradually increases along the pseudopodia, forming a triradiate spicule. By further branching and anastomosis, the branches of the spicule meet and fuse at the tips of their processes (Fig. 3, No. 3), thus building up a hard tissue (stereom), showing a strongly

[1] Although no observations have been made upon the early details of plate deposition (stereom formation) in the Crinoidea, the growth of the plate from the primary spicule on so closely parallels that in the Echinoidea that there can be no doubt concerning the method of formation.

[2] Composition of crinoid skeletons: ref. 25, p. 31; ref. 14, p. 488; ref. 17.

[3] Stereom formation: ref. 34.

reticulated structure (Fig. 3, No. 4) when sectioned in any direction. The co-ordination of deposition is such that each plate acts optically and mineralogically as a single crystal of calcite, without other planes of weakness than the cleavage planes developed by crystallization. The margins of the plates are at first rough with sprouting spicule branches (Fig. 2, No. 2, R), but later, upon coming into mutual contact, become smooth (Fig. 2, No. 5). Growth by branching and anastomosis gives way to interstitial growth,[1] and the increase in size is more gradual. Each plate, as

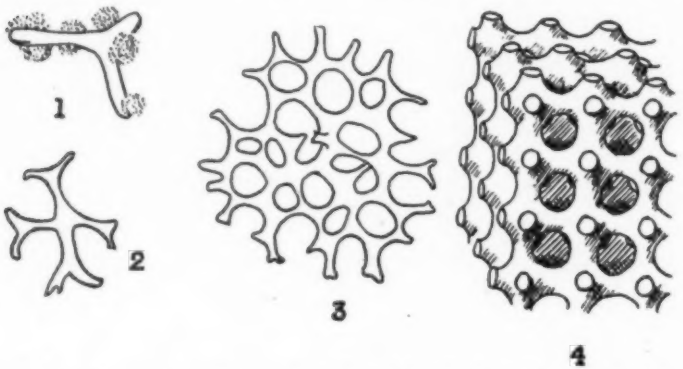

FIG. 3.—Stereom formation: 1, formation of the triradiate spicule by the fusion of seven calciferous cells; 2, basal from a larva of *Antedon* on the sixth day; 3, basal on the tenth day; 4, ideal representation of regular, reticulate stereom. (1, after Theel; 2, 3, after Bury; 4, after P. H. Carpenter.)

it now enlarges, is carried relatively outward and away from the adjacent plates, and in the basal cycle not only away from the adjacent plates, but also away from the axial canal, as is shown by growth lines whenever present. When growth of the plates is symmetrical, each plate in a cycle is the equivalent in size and shape of every other plate in that cycle, and has the same angles with reference to the central axis of the cup as the other plates in the cycle.

b) Reduction of parts by absorption.—This also is a function of ameboid cells, which are similar in appearance to the calciferous

[1] Ref. 35, p. 538.

cells, but take the calcareous salts into solution and transmit them to the deposition cells.[1] When reduction by proximal or distal, or proximal and distal, absorption is symmetrical throughout a cycle of plates, the relation of parts is not disturbed, unless the reduction

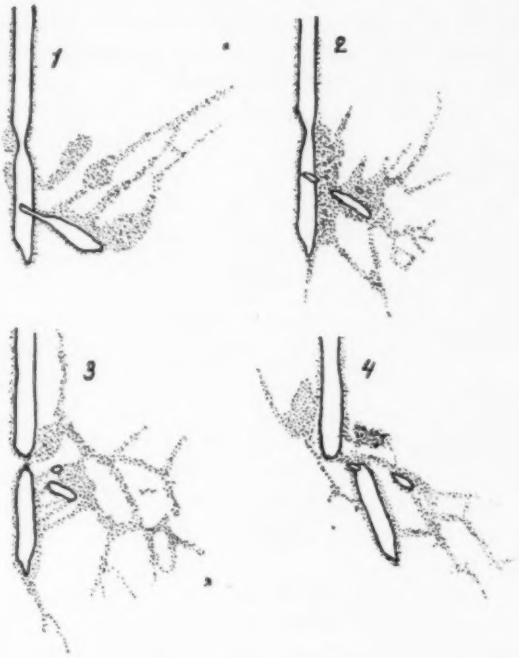

FIG. 4.—Stereom absorption; absorptive cells operating upon the posterior end of a calcareous rod in a mature pluteus: 1, one portion of rod separated, the second partially cut; 2–4, advancing stages up to the nearly completed absorption of portion one, the separation of portion two (after Theel).

of the cycle is complete, thus bringing previously separated cycles into apposition with each other.

c) Anchylosis.—Anchylosis is the uniting of apposed plates by an unbroken deposit of stereom in the sutures, and is, as far as we know, an ontogenetically repetitive process, taking place only

[1] Ref. 34, pp. 349–351.

between plates and not between their formative cell groups. The intrasutural deposit is formed through the activity of the ameboid, calciferous cells, and the firmness with which the plates are united depends upon the amount of stereom deposited. In youth the deposit is slight, the plates are easily separated, and the sutures are usually discernible as external or sometimes as internal grooves. In age, however, much variation exists, for the extent of deposition depends upon the stage of development reached by the group and upon the vitality of the individual. In some cases immature (incomplete) anchylosis is apparently an adult characteristic and the plates are easily separated.[1] In other cases the deposit is as strong as the stereom of the plates, and fracturing results as readily in the plates as in the old suture plane. Again, in cases where firm union is the rule, as in the Camerata, lowered vitality, or other physiological disturbance, sometimes results in the partial or total inhibition of anchylosis. Such abnormalities, or reversions, are of great value in determining the position of sutures otherwise untraceable, and will be more fully considered under the topic of delayed anchylosis.

From the foregoing definition of anchylosis the conclusion is drawn that any suture or group of sutures appearing in the primitive basal cup may be lost through anchylosis, and the following discussion will show the actual and possible combinations due to simple anchylosis alone.

In order to facilitate this description and the tabulation of the variations to be cosidered, the convention of lettering the basal plates from the posterior to the right-posterior, in an anticlockwise direction, has been adopted, the letters separated by dashes making up the basal formula. The letters from *a* to *e* denote the plates and the dashes the intervening sutures; a dash over a letter shows trunkation of that plate, while the absence of a dash between the letters denotes the absence of the suture between those plates. Thus, *a*—*b*—*c*—*d*—*e*— is the formula for the simple, pentagonal base while $\bar{a}$—*b*—*cd*—*e*— shows a hexagonal base with the posterior basal trunkated and the anterior pair of basals united.

[1] Ref. 1, p. 29; ref. 10, pp. 36, 37.

From a study of Figs. 1 and 9 it will be seen that eight types of basal modification, by the reduction in number of the basal plates, occur in the Camerata during the Paleozoic era. The primitive base (*a—b—c—d—e—*), Fig. 1, No. 1, appears in the Ordovician, but it probably originated long before that time. The four-basal type (*a—b—cd—e—*), Fig. 1, No. 2, appears in the Ordovician, becomes abundant in the Silurian, and disappears before the close of the Devonian. The three- inequi-basal type (*ab—c—de—*), Fig. 1, No. 3, makes its appearance in the Ordovician, increases in the Silurian, reaches its climax in the Devonian, and disappears in the Mississippian. The three- inequi-basal type (*ea—bc—d—*), Fig. 1, No. 6, is present during the Silurian, Devonian, and Mississippian, but never becomes very prominent. The one-basal type (*abcde*), Fig. 1, No. 5, occurs at various times during the Paleozoic period, but not as a generic or specific characteristic. The hexagonal, five-basal type (*ā—b—c—d—e—*), Fig. 9, No. 6, is present in the Ordovician. The hexagonal, four-basal type (*ā—b—cd—e—*), Fig. 1, No. 8, appears first in the Silurian (Richmond) and disappears during the Silurian. The three- equi-basal type (*ab—cx—de—*)[1], Fig. 1, No. 10, appears in the Silurian, increases in the Devonian, reaches its climax in the lower part of the Mississippian, and then disappears. The two- equi-basal type (*abc—xde—*),[1] Fig. 1, No. 12, is introduced in the Kinderhook and becomes extinct in the lower part of the Pennsylvanian.

Possible combinations of the primitive five-basals: Since Wachsmuth and Springer have assumed that all crinoids having an unequally tripartite base have the smaller basal in the left-anterior interray, it may be well to consider what combinations may be expected from anchylosis of the primitive five-basals. These combinations are explained below and illustrated in Fig. 5.

Fig 5, No. 1, illustrates the primitive basal cup of pentagonal outline, represented by the formula *a—b—c—d—e—*, and found in *Glyptocrinus*, *Schizocrinus*, *Stelidiocrinus*, and young individuals of *Platycrinus*.

Fig. 5, No. 2, shows a common Ordovician and Silurian type of reduction (*a—b—cd—e—*), in which the two anterior basals are

[1] Formula based upon Wachsmuth and Springer's theory.

anchylosed. In this group there are five possible combinations: *ab—c—d—e—*, *a—bc—d—e—*, *a—b—cd—e—*, *a—b—c—de—*, and *ea—b—c—d—*. Of these combinations, *a—b—cd—e—* has been the only one described in the four-basal Melocrinidae; however, the writer has found the *a—bc—d—e—* (No. 2*a*) combination in the following specimens in the Springer collection: of eight specimens of *Melocrinus calvini* from Calloway County, Missouri, four

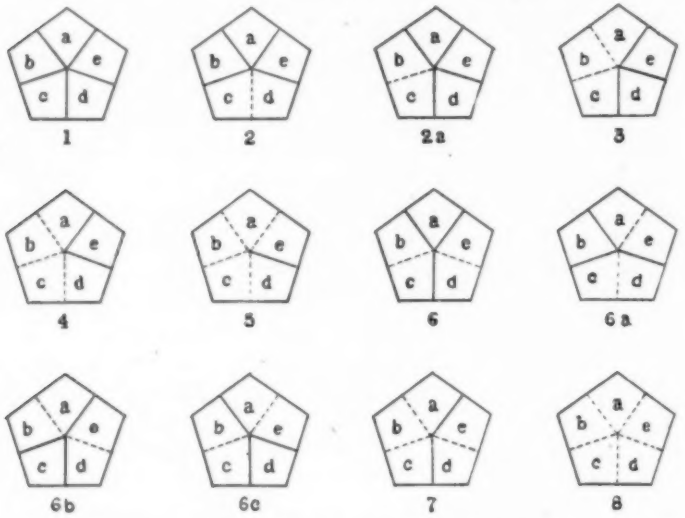

FIG. 5.—Diagrams illustrating types of the possible combinations due to anchylosis of two or more of the primitive five-basals.

could be properly oriented[1], and these showed the *bc* anchylosis (Pl. II, No. 4), as did two specimens of *M. obconicus*? Hall, and one of the type specimens of *M. roemeri*. The other four-basal forms of the Melocrinidae(?) and the Eucalyptocrinidae[2] have the *a—b—cd—e—* type of base.

Fig. 5, No. 3, illustrates a type in which three adjacent basals have been anchylosed (*abc—d—e—*). Here again five combinations

[1] In orienting these specimens the anal tube was used as the reference point.

[2] This orientation of *Eucalyptocrinus* is strictly arbitrary, as no indices for proper orientation have as yet been discovered.

are possible: *abc—d—e—*, *a—bcd—e—*, *a—b—cde—*, *b—c—dea—*, and *c—d—eab—*. Of these combinations one, the *abc—d—e—* combination, is found in *Zophocrinus*, as figured. This orientation does not agree with Bather's interpretation of the genus,[1] but is based upon the discovery of the anus in a large number of specimens studied by the writer in the Springer and Walker Museum collections.

Fig. 5, No. 4, shows the anchylosis of four adjacent plates (*abcd—e—*), leaving but one free plate. Here, however, any plate of the five might have been the free plate, and five combinations are possible: *abcd—e—*, *a—bcde—*, *b—cdea—*, *c—deab—*, and *d—eabc—*. Of these combinations none have been discovered.

Fig. 5, No. 5, illustrates one of five possible combinations in which only one suture exists (*abcde—*). Combinations 4 and 5 seem too asymmetrical from a structural viewpoint to occur as either generic or specific characters, but might appear in cases of delayed anchylosis, in which complete anchylosis is the normal result.

Fig. 5, No. 6, illustrates the simple tripartite combination (*ab—c—de—*), in which two pairs of basals are anchylosed. Of the five possible combinations of this type four are now known: *a—bc—de—*, in *Allagecrinus americanus;*[2] *b—cd—ea—*, in *Storthingocrinus*[3] and *Hyocrinus* (No. 6, *a*)[4]; *ab—c—de—*, in *Sybathocrinus* and the Platycrinidae (No. 6, *b*); *bc—d—ea—*, in *Hapalocrinus*[5] and *Stephanocrinus*[6] (No. 6, *c*). The fifth combination (*ab—cd—e—*) has not yet been discovered.

Fig. 5, No. 7, illustrates one of the five possible combinations in which three- and two-basals are anchylosed, as *abc—de—*, etc. Of these only one is known, *abc—de—* in *Mycocrinus*,[7] as figured.

Fig. 5, No. 8, shows the complete type of anchylosis (*abcde*). While this formula recognizes but one type of complete anchylosis,

[1] Ref. 6, pp. 150, 151.

[2] This combination was found recently, by the writer, in two specimens of *Allagecrinus americanus* in a large collection of that species made by Professor Weller at Louisiana, Missouri.

[3] Ref. 3, p. 426.

[4] Ref. 6, p. 153.

[5] Ref. 21, pp. 95–105, Pls. 9, 10.

[6] Ref. 19, pp. 212, 351.

[7] Ref. 28, p. 110, Pl. 7, Fig. 4.

the type may have been derived by the simultaneous anchylosis of the five primary plates, or from the closure of the remaining sutures in any of the thirty possible combinations given above. Dealing here with results alone, we see that thirty-one possible modifications of the five primary basals are obtainable through simple anchylosis.

[*To be continued*]

EXPLANATION OF PLATES

PLATE I

Teleiocrinus umbrosus Hall. Abnormal specimen cited by Wachsmuth and Springer as confirmation of their theory

No. 1.—Oblique view of posterior interray, showing absence of anal plate and one of the first interbrachials, and the reduction of the right-posterior basal. Basal formula, $ab-cd-e-$; formula of posterior interray, $o-1-3-4-2-$.

No. 2.—View of right-posterior interray, showing normal arrangement of interbrachials $1-2-2-2-$, and reduction of right-posterior basal.

No. 4.—Posterior view.

No. 6.—Tegmen, showing position of anal tube.

Teleiocrinus umbrosus Hall. Springer collection; normal specimens

Fig. 3.—Posterior view, showing normal posterior interray and normal base. Basal formula, $ab-cd-ex-$; formula of posterior interray, $A-2-3-4-1-$. To be compared with Nos. 1 and 4.

No. 5.—Tegmen, showing position of anal tube in another specimen; to be compared with No. 6.

PLATE II

Glyptocrinus decadactylus Hall. Springer collection, specimens having a pentagonal base

No. 1.—Basal view, showing normal pentagonal base with five basals. Basal formula, $a-b-c-d-e-$.

Chicagocrinus inornatus Weller (type). University of Chicago Paleontological Collection, No. 10787

No. 2.—Basal view, showing anchylosis and reduction of antero-lateral basals and compensating enlargement of postero-lateral basals. Basal formula, $a-b-cd-e-$.

Melocrinus calvini Wachsmuth and Springer. Springer collection

No. 3.—Posterior view.

No. 4.—Basal view of same specimen, showing anchylosis and reduction of sinstro-lateral basals and compensating enlargement of posterior and right-anterior basals. Basal formula, $a-bc-d-e-$.

Stephanocrinus angulatus Conrad. University of Chicago paleontological Collection, No. 10787

No. 5.—Basal view, showing anchylosis and reduction of right-posterior and posterior and sinstro-lateral basals, and compensating enlargement of right-anterior basal. Basal formula, *ea−bc−d−*. Note reduction of right-posterior and left-anterior radials.

Platycrinus subspinosus Hall. Springer collection

No. 6.—Basal view, showing normal *Platycrinus type of anchylosis*. Basal formula, *ab−c−de−*. To be compared with No. 5.

Abacocrinus tesselatus Angelin. Springer collection, specimens having a hexagonal base

No. 7.—Basal view, showing asymmetry of posterior radials, enlargement and trunkation of posterior basal, and anchylosis and reduction of antero-lateral basals, coupled with compensating enlargement of postero-lateral basals. Basal formula, $\bar{a}-b-cd-e-$.

Melocrinus sampsoni M. and G. (type). University of Chicago paleontological collection, No. 6958; probably *Actinocrinus chouteauensis* S.A.M.

No. 8.—Basal view showing reappearance of anterior basal suture. Basal formula, *ab−c−d−ex−*.

Batocrinus. University of Chicago paleontological collection No. 9082

No. 10.—Basal view of normal specimen. Basal formula, *ab−cd−ex−*.

No. 11.—Basal view of abnormal specimen, showing reappearance of anterior basal suture. Basal formula, *ab−c−d−ex−*.

Actinocrinus multiradiatus. University of Chicago paleontological collection No. 8959

No. 9.—Basal view with base removed, showing asymmetry and reduction of posterior radials. Compare with Nos. 7–14.

Steganocrinus pentagonus Hall. Springer collection

No. 12.—Basal view of normal specimen, showing asymmetry and reduction of posterior radials. Basal formula, *ab−cd−ex−*.

No. 13.—Basal view of abnormal specimen, showing loss of the antero-lateral and posterior basal sutures and the reappearance of the anterior and left-posterior sutures. Basal formula *bc−dea−*; factor *x* may or may not be present.

No. 14.—Basal view of another abnormal specimen, showing loss of right-anterior basal suture and reappearance of anterior suture. Basal formula, *ab−c−dex−*.

No. 15.—Basal view of abnormal specimen, University of Chicago paleontological collection, No. 8979, showing loss of anal plate. Basal formula, *b−cd−ea−*. See Plate III.

PLATE III

Steganocrinus pentagonus Hall

No. 1.—Posterior view of abnormal form of Pl. II, No. 15.

No. 2.—Tegmen of same specimen, showing position of anal tube.

No. 3.—Posterior view of normal specimen in Springer collection. To be compared with No. 1.

Hexacrinus elongatus Goldfuss. Springer collection

No. 4.—Basal view of normal form. Basal formula *ab—cd—ex—*. Note reduction of posterior radials.

Hexacrinus anglypticus Goldfuss. Springer collection

No. 5.—Basal view of abnormal form, showing loss of posterior basal suture and reappearance of left-posterior suture. Anchylosis of anterior basals normal. Basal formula, *b—cd—ea—*; factor *x* may or may not be present.

No. 6.—Basal view of another abnormal specimen, showing loss of right-anterior basal suture and reappearance of anterior suture. Basal formula, *ab—c—dex—*.

Talarocrinus patei M. & G, Springer collection

No. 7.—Basal view of normal specimen. ×2. Basal formula, *abc—dex—*.

No. 8.—Basal view of abnormal specimen, showing reappearance of left-posterior basal suture. ×2. Basal formula, *a—bc—dex—*.

No. 9.—Basal view of another abnormal specimen, showing reappearance of left-anterior basal suture. ×2. Basal formula, *ab—c—dex—*.

No. 10.—Basal view of another abnormal specimen, showing loss of posterior basal suture and reappearance of left-posterior and right-anterior sutures. ×2. Basal formula, *bc—d—ea—*. Factor *x* may or may not be present.

Pterotocrinus cirnarius Lyon, Springer collection; Tegmen figured by Wachsmuth and Springer, ref. 39, Pl. LXXIX, Figs. 7*a*, 7*b*

No. 11.—Basal view, showing great reduction of anal plate, and asymmetry of posterior radials. Basal formula, *abc—dex—*.

Dichocrinus inornatus W. and Sp. Springer collection

No. 12.—Lateral view of normal specimen. ×1½.

No. 15.—Tegmen of normal specimen showing flexible condition of anal tube and interambulacral areas. ×2.

Platycrinus symmetricus W. and Sp. Springer collection

No. 13.—Lateral view, showing similarity to No. 12. ×1½

No. 14.—Tegmen of young specimen, figured by ref. 39, Pl. LXIX, Fig. 1*c*. Note flexible condition of anal tube and interambulacral areas, and general similarity to No. 15. ×2.

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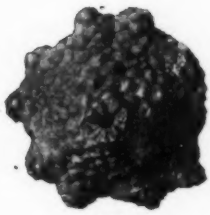

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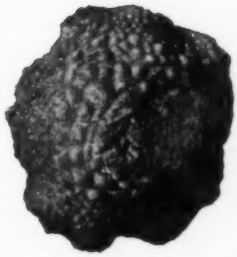

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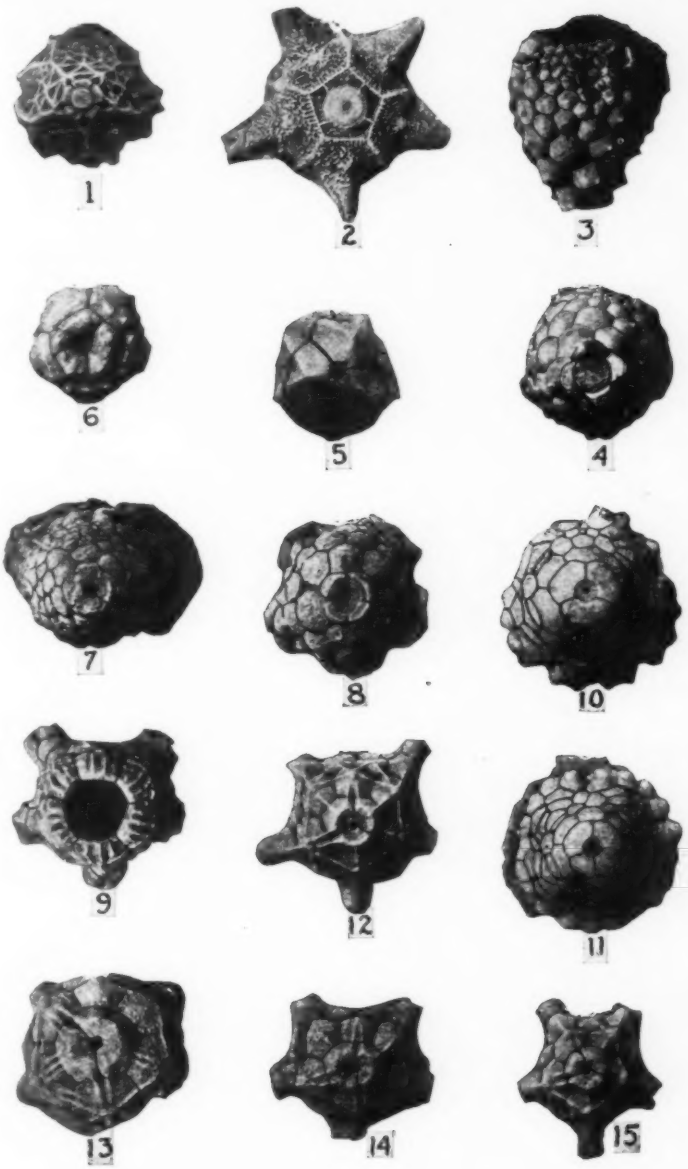
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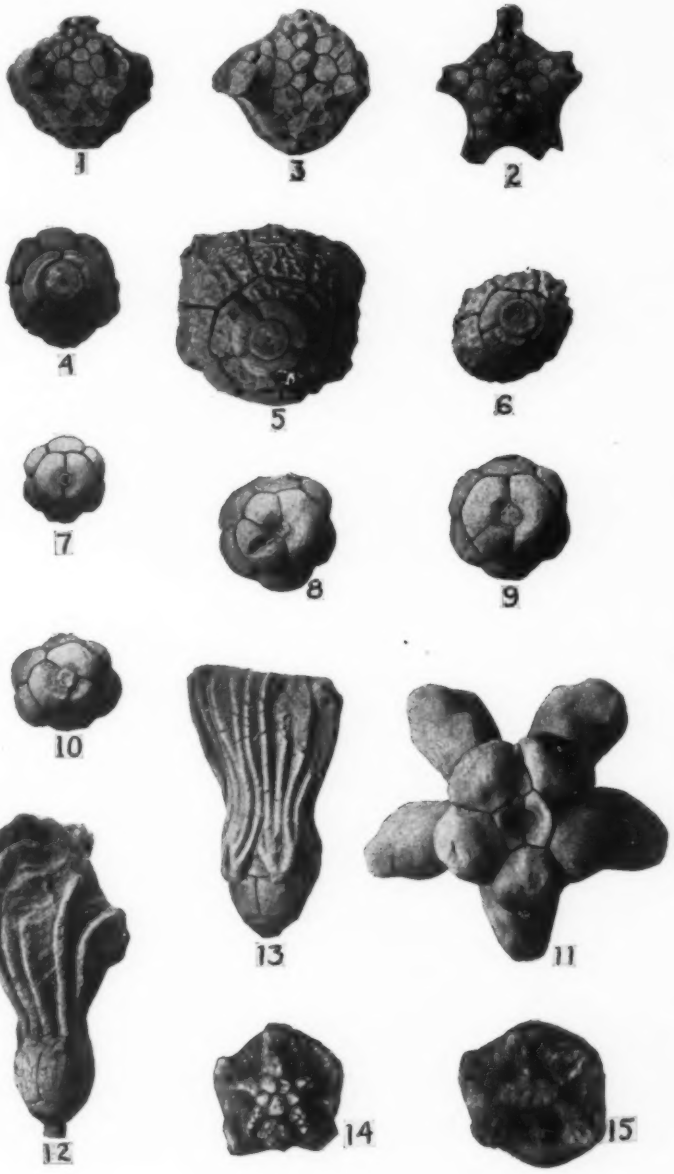
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VARIATIONS OF GLACIERS. XX[1]

HARRY FIELDING REID
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The following is a summary of the *Nineteenth Annual Report* of the International Committee on Glaciers.[2]

THE REPORT OF GLACIERS FOR 1913

Swiss Alps.—Sixty-one glaciers were measured in 1913; a larger proportion were retreating this year than in 1912. The Rhone Glacier, however, has grown in thickness, throughout, with an increase of velocity and an advance of the tongue.

Eastern Alps.—The summer of 1913, like its predecessor, was very wet, especially on the north side of the Alps; the conditions during both summers must have influenced the glaciers in 1913. Of the 37 glaciers observed 8 were advancing, 4 were stationary, and only 25 continued their retreat. The increase in the number of advancing glaciers is certain, and the retreat of the glaciers of the Eastern Alps has diminished; it is doubtful if the retreat can now be said to be the prevailing condition.

Italian Alps.—In the Piedmont Alps the snowfall has been too heavy to permit of good observations, but the glaciers are apparently retreating. Careful photographic surveys have been made of three of the large glaciers on the south side of the Mount Blanc massif; these glaciers are retreating; but the snowfall in the higher regions has increased, so much so in places as to cause a marked change in the appearance of the mountains. In the Monte Rosa group the observed glaciers were retreating. In the Lombard Alps some glaciers were making slight advances, some slight retreats. On the whole, the large glaciers of the Italian Alps were retreating, but a number of the smaller ones were slightly advancing or were in a doubtful condition.

[1] Earlier reports appeared in the *Journal of Geology*, Vols. III–XXIII.

[2] *Zeitschrift für Gletscherkunde*, IX (1914), 42–65.

Swedish Alps.—But one glacier, the Mikka, was observed, and it showed no change.

Norwegian Alps.—All the 16 glaciers examined in the Folgefon and the Jostedalsbrae were retreating with one exception. On the other hand, in the Swartisen, the Okstinderne, and the Frostisen, 7 glaciers were advancing, one retreating, and two were stationary.

Russia.—Observations in the Caucasus and in Turkestan have laid the basis for the determination of future changes. One glacier in the Caucasus was retreating and two were stationary.

Canada.—No observations have been recorded in the last two years;[1] but during the few years before 1910 the Illecillewaet, the Asulkan, the Victoria, and the Yoho glaciers were all retreating. Shortly before 1909, however, the Asulkan made an advance.

Himalaya.—The greater part of the information collected refers to variations which occurred some years ago. The positions of the ends of many glaciers were determined in 1906, but later observations are not available. At that date there was evidence that the glaciers were generally retreating.

New Zealand Alps.—Here also observations are scanty. For about ten years after the middle of the nineties, several of the larger glaciers advanced. Later conditions have not been reported.

REPORT ON THE GLACIERS OF THE UNITED STATES FOR 1914

Mr. F. E. Matthes sends me the following information:

The snowfall during the winter of 1913–14 in the Sierras was so heavy that the glaciers were still completely covered at the end of September; the snow extended even beyond some moraines which encircle the glaciers at a short distance. These moraines are recent; the youngest is comparable to the moraines which marked the advance of the Alpine glaciers at the end of the eighteenth and the beginning of the nineteenth centuries. Historical evidence is not available to determine the actual time when these moraines were formed; but the presence of big trees (*Sequoia Washigtoniana*) near the glaciers may supply the information; for their rings of growth contain a trustworthy record of the climatic fluctuations of the last three thousand years.

[1] The last report on the Canadian glaciers in this series was in *Variations of Glaciers*, XIII, report for 1906. See *Journal of Geology*, XVI (1908), p. 665.

Professor Lawrence Martin sends me the following information regarding the Alaskan glaciers:

College Fiord.—Miss Keen visited Prince William Sound during the summer of 1914 for the exploration of the Harvard Glacier, and made careful observations of the variations of a number of other glaciers.[1] She found that the Harvard Glacier is 18 miles long, or about 28 miles if the Brunonian Glacier tributary is included. It rises at an elevation of about 7,500 feet. The eastern side of the end of Harvard Glacier seems to have retreated slightly between 1910 and 1914, but the western edge near Radcliffe Glacier was still advancing. There was no observable change in Downer, Baltimore, and Smith glaciers. Bryn Mawr may have retreated slightly; the barren zone at its northern border was widest, but the evidence was conflicting, for a shrub north of the glacier was being overturned at the time of Miss Keen's visit. Vassar Glacier was more crevassed in 1914 than in 1910, but had not advanced appreciably; Wellesley Glacier had retreated slightly; Yale Glacier seems to have advanced a little; Barnard had a slight forward movement.

Harriman Fiord.—The recession of Barry Glacier, observed in 1913, continued in 1914. The total recession of different parts of the ice front, from 1910 to September 25, 1914, was 3,000–7,000 feet. Cascade Glacier was nearly independent of the Barry in 1914. Of the other ice tongues in Harriman Fiord the Baker Glacier advanced at least 1,000 feet between 1910 and 1914, and spread considerably at both borders. The Harriman and Roaring glaciers seem to be still advancing. A small unnamed ice mass on the slopes of Mt. Muir moved forward slightly. The Surprise, Cataract, Serpentine, Toboggan, and Dirty glaciers were unchanged.

Eastern Prince William Sound.—The Valdez Glacier, continuing its long-maintained recession, melted back about 200 feet from 1909 to August 10, 1914. Shoup Glacier advanced very slightly. Columbia Glacier, the largest ice tongue in Prince William Sound, is also the most interesting, for it has continued the slow forward movement that has been in progress since before 1908. Miss Keen found that the eastern border advanced 1,500 feet between 1910 and September 30, 1914, and spread laterally; in other parts the advance was less, being perhaps 1,300 feet on Heather Island. Photographs of Childs Glacier, by Robert Sewall, show that in July, 1914, its northern border was retreating.

Southeastern Alaska.—It was reported in the Juneau papers that Norris Glacier, in Taku Inlet, had made a considerable advance. A photograph of the Taku Glacier, taken about 1907, shows a distinct advance since 1890.

Dr. Martin has tabulated the snowfall and temperature as recorded at several Alaskan stations. He finds not only great differences in different years, but the years of maximum snowfall

[1] *Bulletin of the American Geographical Society*, XLVII (1915), 117–19.

at the various stations are different, so that it is not safe to draw any detailed conclusions about the snowfall in the mountains from the records at the stations; though the general trends are the same. The annual snowfall at Killisnoo, somewhat more than one hundred miles southeast of Muir Glacier, between 1891 and 1896 was about twice as great as it has been since then; but the glaciers do not show corresponding variations. Temperature records have been kept at Sitka, with two short intermissions, since 1828. The average temperature for the five months from May to September in the years 1828–77 and in the years 1906–13 differs by only one-tenth of a degree Fahrenheit. The average temperature at Juneau for the same months during the years 1906–13 is about 2° F. higher than during the years 1883–96. It does not seem possible to infer any definite relations between temperature and glacier variations from these records.

The United States Geological Survey has published a map of a portion of the Chugach Mountains, northeast of Prince William Sound, on a scale of about one inch to the mile (Port Valdez District, Alaska; sheet 602 B). It shows a large area of glaciers and snowfields. Parts of the Columbia, Shoup, and Valdez glaciers appear on it. Unfortunately the contours are not carried over the glaciers, but the altitudes of a number of points are indicated so that marked future changes in the thickness of the ice will be determinable. Other new maps of Alaskan glaciers cover the Haganita-Bremner region, northeast of the Copper River Cañon,[1] the Bering Glacier, and the western border of the Malaspina Glacier at Icy Bay,[2] and part of the Kenai Peninsula.[3] An excellent topographic map, on the one-inch scale, showing all the glaciers and their relations to the mountains and rivers, accompanies M. C. Campbell's *Popular Guide to the Glacier National Park*.[4] Pamphlets containing popular accounts of the glaciers of Mount Rainier and of Glacier National Park have been issued by the Department of the Interior.[5]

[1] *Bull. U.S. Geol. Surv. No. 576*, Plate I.

[2] *Bull. U.S. Geol. Surv. No. 592*, Plate IV.

[3] *Ibid.*, Plate VIII.

[4] *Bull. U.S. Geol. Surv. No. 600.*

[5] *Mount Rainier and Its Glaciers*, by F. E. Matthes; *Glaciers of Glacier National Park*, by W. C. Alden.

Reviews

Climates of Geologic Time. By CHARLES SCHUCHERT. Carnegie Institution of Washington, Publ. No. 192, pp. 263–98, Figs. 87–90.

There has been a progressive advance, in late years a most rapid one, from the conception of a former hot, dense, vaporous earth atmosphere, the natural corollary of the Laplacian hypothesis. Knowledge of glacial climates, which had its beginning in studies in the Alps early in the eighteenth century, has grown until not only has there been demonstrated a world-wide lowering of temperature with glaciation of much of the Northern Hemisphere in recent geologic time, but there has been proved as well a number of such glacial periods in earlier times. The cold climates which have periodically affected the earth more or less widely since the beginning of geologic history have been of short geologic duration. The data at hand indicate at least four well-marked glaciations: (1) earliest Proterozoic, shown by the widespread "slate conglomerates" at the base of the Lower Huronian in Canada; (2) latest Proterozoic, marked by thick, widespread tillites beneath the Lower Cambrian of Southern Australia, and by the Gaisa formation of Northern Norway, both now thought to be latest Proterozoic instead of Lower Cambrian; (3) Permian, abundantly proven by tillites in many parts of the world, mostly between latitudes 20° N. and 40° S.; and (4) Pleistocene, the deposits of which mantle much of the Northern Hemisphere. Less well-marked cold periods seem to have occurred (5) at another part of the Proterozoic, for the glacial materials of this age in South Africa represent neither the earlier nor the later part of the era; (6) in the Lower Devonian of South Africa, shown by the Table Mountain series, and (7) in the early Eocene, indicated by deposits in the San Juan Mountains of Colorado. The greatest reductions of temperatures, so far as known, varied between the hemispheres.

Guided by the postulate that the living things of sea and land always have been affected by climatic conditions much as now, climate variations are to be observed in the succession of plants and animals recorded as fossils. In addition, the color and general character of the sedimentary deposits afford light on climatic conditions at the time of their

deposition. In spite of widespread glaciation at certain periods, the Proterozoic era had, in the main, a rather warm, equable climate. This is shown by the enormously thick limestone deposits (50,000 feet in Canada), abundance of large Archaeocyathinae, widely distributed graphites, and presence of coal. The Cambrian, with an abundance of shallow-water life, had a uniformly warm temperature which continued into the Ordovician and Silurian. The red shales, gypsum deposits, salt beds, and scant, depauperate fauna of the late Silurian indicate aridity and possible coolness, the latter expressed perhaps by local glaciation (South Africa). The deposits of Northern Europe in the Devonian probably marked a cool, somewhat arid climate, and the great change in the life-forms in the Middle Devonian may be further evidence of the same thing. The climate of the middle and later part of the Devonian was warm; that of the Carboniferous, warm-temperate to subtropic. The great variety of marine life, abundance of reef corals in high latitudes, extensive coal deposits, subtropical flora, and large-sized insects, all suggest this. The adverse climate of the Permian is clearly shown in the glacial tillites, red shales, salt and gypsum deposits (to thickness of 3,300 feet), and depauperate, scanty fauna. The sweeping change in the types of life seen in the Triassic is most convincing proof of climatic severities at this time. Large trees (to 8 feet diameter), and their absence of rings, luxuriant ferns, and thick deposits of limestones in high latitudes, all suggest warmth. The late Triassic-Lias probably saw a reduction of temperature, for of the Triassic ammonites (1,000 species) none passed into the Jurassic, the insects were uniformly dwarfed, and the corals, both numerically and geographically, were very much restricted. The Jurassic was a period of remarkably warm, equable climate. The wide distribution and variety of ammonites (15,000 species), their presence with corals and marine saurians in very high latitudes, and the very cosmopolitan, luxuriant floras are to be noted. The Comanchean-Cretaceous marks the introduction of hardwood forests and may indicate a cooler climate than the Jurassic; but the presence of magnolias in Greenland and Alaska shows at least warm-temperate conditions there. The Cretaceous is distinguished by a remarkable deployment of the immense land reptiles and very thick limestone deposits. Climatic conditions in the Tertiary are not sharply different from those of the Cretaceous. Middle and late Eocene floras show many tropical marks, Oligocene faunas are varied and large sized, especially the foraminifers (nummulites), the Miocene shows a distribution of warm-temperature plants in Spitzbergen and Grinnell Land, but the late Miocene was, at

least in many places, cooler. The Pliocene was rather warm but undoubtedly became colder toward the beginning of the Pleistocene when glacial conditions reached full expression.

The author concludes that the marked climatic variations of the past are primarily due to periodic changes in the topography of the land surface, modified by the variations in the amount of heat stored in the oceans, and the change in the composition of the atmosphere which conditions the storage of solar radiation. Supplementary notes with quotations from original descriptions of pre-Permian tillites and a bibliography of the subject are appended.

R. C. M.

Oceania. By P. MARSHALL. Handbuch der regionalen Geologie, 5. Heft, Band VII, Abteilung 2. Heidelberg, 1912. Pp. 36, figs. 10.

Oceania, limited on the west by the Marianne, Pelew, and Caroline islands, on the east by the Sandwich Islands, is a region measuring about 8,400 miles east and west, and 4,200 miles north and south. Most of the islands are small, aggregated in rather well-defined groups or lines, and within the limits of each group the geological and physical structures are somewhat uniform. With the exception of the largest only, the islands are volcanic or composed of coralline limestone, and almost every island is fringed by coral reefs. The basin of the Pacific is of great, and nearly uniform, depth (2,500–3,000 fathoms), but in the west part of Oceania the ocean depths are far less regular. Very deep troughs are found subparallel to some of the island chains and their connecting submarine ridges, and the location of the shallows and basins is suggestive of important structural relations. The island chains seem to define at least four mountain ranges which are seen to converge toward Northern New Zealand, a region therefore of great structural importance. The true border of the Pacific basin segment of the earth's crust is marked by a fairly definite line, indicated by the submarine elevations, areas of raised coral rock, and the distribution of andesitic rocks. This line passes through the Kermadec, Tonga, Fiji, New Hebrides, and Solomon islands, and is noteworthy as the belt of present volcanic activity. Triassic fossils in New Zealand and New Caledonia indicate their coastal connection in the past, and the present faunal and floral distribution is strongly suggestive of the former existence of a continental area limited by the island line mentioned. Coral growths of the Pacific

generally imply considerable subsidence, though in places this has been superseded by elevation. A brief description of the physical character and geology of each of the island groups, so far as known, comprises the central part of the paper. A bibliography of the subject is appended.

R. C. M.

Geology of the Gold Belt in the James River Basin, Virginia. By STEPHEN TABER. Virginia Geol. Surv., Bull. No. VII, 1913. Pp. 271, figs. 23, maps 2, pls. 8.

The gold mines are localized mainly in Goochland and Fluvanna counties. Free gold occurs in quartz veins which cut pre-Cambrian quartzites, schists, and gneisses. The gold seems to be associated with granite intrusions, possibly of Cambrian age.

The author suggests that this district illustrates the formation of quartz veins by the force of crystallization. The value of the gold produced in this region amounts to about $6,000.00 per annum.

T T. Q.

Pre-Cambrian Algonkian Algal Flora. By CHARLES D. WALCOTT. Smithsonian Misc. Coll., LXIV, No. 2, 1914. Pp. 153, pls. 19.

Fossil algal flora, produced by blue-green algae, are found in the Algonkian formations of the Cordilleran region. Walcott describes and figures 8 new genera and 12 new species of algae from the Belt series.

Before the discussion of the algal remains, there is a discussion of the continental conditions and sedimentation of Algonkian times. From Robson Peak, British Columbia, to Arizona and southern California, a distance of over a thousand miles, there is a marked Algonkian-Cambrian unconformity. Preceding this advance of the Cambrian sea, the Algonkian was a time of continental elevation and of largely terrigenous sedimentation in non-marine bodies of water; also there was some subaerial deposition. Marine sediments accumulated along the shores of the continents, but they are now far buried, and everywhere lost to our knowledge. This unknown marine life, preceding the Cambrian invasion, belongs to what the author calls "Lipalian" time. Red sandstones and shales in the west suggest an arid and, possibly, a cold climate. The thick limestones in the western interior are explained as having been deposited from non-marine waters by algae.

T. T. Q.

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